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**THE DIFFUSION OF
NEW CONSUMER DURABLES
AND
THE ROLE OF ADVERTISING**

By

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SUMMARY

Existing economics literature, especially empirical, on the role of advertising in the diffusion process is sparse. In this thesis, explicit attention was given to the part played by advertising in the diffusion of new consumer durables, both at a theoretical and empirical level. The two competing epidemic and probit demand diffusion models were used and two period models established. Advertising was incorporated into each framework, becoming endogenous once a supply side was added. The resulting profit maximising advertising sales ratio within each model was compared and contrasted to the standard Dorfman-Steiner and Nerlove-Arrow conditions found in the literature. The special features of the models did impinge upon these ratios. Alternative supply structures (defined in terms of number of firms) were considered and the resulting effects on the industry advertising sales ratio within each demand framework explored. The results could not be rigorously shown, however the essence of each of the demand frameworks had potentially different implications for the monopoly as compared to oligopoly outcome. The existence of a positive generic information externality in the epidemic model, reducing the advertising intensity once the monopoly assumption was relaxed, whilst the negative early extraction effect and intertemporal price discrimination opportunities in the probit model could increase the advertising sales ratio in an oligopoly industry.

Two new consumer durables were chosen for the empirical investigation, the video cassette recorder and the colour television receiver. Both demand diffusion models were applied to the data for each product using OLS estimation procedures. It was found that the epidemic model performed relatively better to the probit model for the video cassette recorder, indicating a positive and statistically significant role for advertising, when entering indirectly through the social contact coefficient. Thus the information variables took precedence for this particular product. However there was some question over the predictive ability of the model and no account was taken of any possible simultaneous equation bias that would arise if advertising was endogenous, as suggested in the theoretical chapters. In contrast, the probit model performed relatively better for the colour tv receiver, showing the importance of the economic variables such as relative price, hire purchase restrictions and total advertising messages, in addition to the existing owners to non owners explanatory variable. This conclusion was reached after recognition of the possible existence of simultaneous equation bias. The information about the advertising decision contained in the theoretical chapters was used to identify the instrumental variables to include in the TSLS estimation procedure. However, restricting the sample period to the first 11 years of the diffusion process cast some doubt upon the probit model specification. This might indicate that future work should consider incorporating information variables into the probit structure in a more satisfying manner.

ABBREVIATIONS

AS₁	Advertising sales ratio in period 1.
AS₂	Advertising sales ratio in period 2.
AR2	Adjusted R².
BBC	British Broadcasting Corporation.
BREMA	The British Radio and Electronic Equipment Manufacturers Association.
CHOW	Chow test for stability of the regression coefficients.
CUSUM	Cumulative Sum of Recursive Residuals.
CUSUMSQ	Cumulative Sum of Squares of Recursive Residuals.
D-S	Dorfman Steiner.
DW	Durbin-Watson statistic for 1st order serial correlation.
H & S	Horsky and Simon.
HET	Heteroscedasticity test based on regression of squared residuals on squared fitted values.
HP	Hire Purchase.
ITV	Independent Television.
LHS	Left Hand Side.
LM4	Lagrange Multiplier test for residual autocorrelation up to order 4.
MAD	Mean Absolute Deviation.

MINTEL	Market Intelligence.
MSE	Mean Square Error.
N-A	Nerlove Arrow.
NLS	Non Linear Least Squares.
NOB	Number of observations.
NORM	Jarque-Bera test for normality.
OLS	Ordinary Least Squares.
PRED	Predictive Failure Test, ie, Chow's second test of adequacy of predictions.
R & D	Research and development.
RHS	Right Hand Side.
RPI	Retail Price Inflation.
RSET	Ramsey Reset test using the square of the fitted values.
RSS	Residual Sum of Squares of the equation.
S & S	Simon and Sebastian.
SE	Standard Error.
TSLs	Two Stage Least Squares.
TV	Television.
UK	United Kingdom.
UN	United Nations.

US **United States of America.**

(or USA)

VAT **Value Added Taxation.**

VCR **Video Cassette Recorder.**

wrt **With respect to.**

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The traditional comparative static approach of economic analysis, although informative and useful, can tend to obscure some important implications for an economy that in reality is in a continual process of change. The focus of attention in the static approach is the comparison of equilibrium positions. Little if any knowledge is gained about the process of transition between the two static equilibrium points. Writers working outside of mainstream economics, such as those belonging to the Austrian school of thought, have always challenged this view and for them the process itself is the essential subject of enquiry. More recently, interest in the phenomenon of disequilibrium at the macro level of an economy has led to the development of temporary equilibrium models. Of course empirical research has also had to concern itself with the process of transition between two equilibrium states, an example being the use of an adjustment mechanism in investment equations.

1.2 TECHNOLOGICAL CHANGE

The equilibrium concept is fundamental to neoclassical economics and consequently technological change has almost been relegated to the periphery because of the difficulty of its incorporation into the neoclassical approach. As a result, technological progress has often been treated as an exogenous event. Yet technological change is one of the major factors affecting economic activity and welfare. Just how considerable the benefits can be, was demonstrated in the well known study by Solow (1957). He concluded that approximately 7/8 of the increase in labour productivity in the US over the period 1909 to 1949 was attributable to technical change. Of course, this was a rather narrow view of the benefits of innovation, concentrating as it did on the cost decreasing aspects of new process technologies. The potential increase in consumer

welfare due to product innovations was not addressed. Nonetheless, the considerable impact of technological change is unquestionable, so it is gratifying to note its re-emergence as an area of interest for economists in recent years.

1.3 DIFFUSION

However, some issues of technological change have received more attention than others. Schumpeter (1934) suggested 3 stages in the process of technological change which have remained popular; invention, innovation and diffusion. A considerable amount of work has focused on innovation, with R & D being adopted as the variable most associated with this stage. Obviously this aspect is important but the overall economy wide benefits of technological change occur as diffusion of the innovation takes place, that is, as its use or acquisition spreads through the economy. These benefits can be considerable. Just taking the period since the second World War, many consumer durables have emerged which at the outset were confined to a small and privileged group of consumers. However within a relatively short space of time, the innovation has come to be enjoyed by the mass of the population in the economy. The monochrome television receiver is a good example (quoted in the appendix to Chapter 6). Within about 20 years of its initial commercial appearance, at least 86% of UK households had acquired the product.

1.4 PRODUCT INNOVATION; THE EXTENT OF NEWNESS

The total effect of the introduction of the monochrome tv on consumer welfare as its use spread, must have been considerable. Of course the magnitude of the benefit may depend upon the extent of newness of the innovation. If the product is revolutionary in the sense that no similar good previously existed, the newness may be fundamental (eg. the video cassette recorder, investigated in Chapter 5). On the other hand, the innovation may be incremental as a similar although inferior product already existed (eg. the colour television receiver, investigated in Chapter 6).

There is an alternative view suggesting that much of the 'newness' of product innovations has been 'fraudulent or related trivially' (Baron & Sweezy 1966). Whilst there may be some examples in which the extent of newness is debatable, the welfare increasing aspects from new major consumer durables, such as the video cassette recorder and colour tv, seem less controversial.¹ In any case, the diffusion process itself, which is so important to the realisation of the economic and welfare benefits arising from technological change (whatever their magnitude), warrants considerable attention within its own right.

In fact this has been recognised in the literature and the study of the diffusion process itself has been growing (Stoneman 1985). Much of the work by economists within this field has been directed towards the analysis of new process technologies, although consumer product innovations have not been completely ignored and, in any case, many of the underlying concepts can be easily transferred from the analysis of one to the analysis of the other, merely necessitating a change in terminology.

1.5 THE ROLE OF ADVERTISING IN THE DIFFUSION PROCESS

1.5.1 Expansionary vs Re-distributive

One consequence of the preoccupation with process innovations has been the relative neglect of advertising in the diffusion process, perhaps because it is generally agreed that advertising has a far more prominent role to play in consumer as opposed to intermediate markets. However even in those diffusion studies specifically devoted to consumer products, advertising has been more or less ignored. This is surprising, for potentially, there is a wide role for advertising to play in a world of product innovation. The diffusion process is, by its nature, a dynamic phenomenon, thus the effects of advertising both at a point in time and over time need to be addressed.

Diffusion models can be applied at a variety of levels of aggregation. Generally with product innovations, the focus of attention is at the economy wide level, the models

¹. Unlike for example, a new toothpaste where the innovating feature is a red stripe running through it.

being used to describe the spread of ownership of the generic product through a population. Consequently, the integration of advertising into such diffusion models means that the approach is similar to previous studies of advertising which have looked specifically at its effect on total market demand (in a static framework), i.e. the investigation of the effect of total advertising by all firms on the demand for a particular product. Such modelling ignores how demand is distributed between rival brands.

This approach contrasts with the generally accepted belief that the predominant effect of advertising is distributive between competitors and thus the more disaggregative the level of analysis, the greater will be the elasticity of demand with respect to advertising.² Such procedures effectively assume a constant total level of demand in order to examine the effect of advertising on market share, in other words, expenditures on advertising are seen as a zero sum game. Of course there has been some consideration given to the opposite approach, whereby the interbrand competitive effects of advertising are ignored so that its effect on total industry demand can be identified (or even at a higher level of aggregation, ignore the inter industry effects to establish advertising's impact on aggregate consumption). Empirical results are conflicting (Schmalensee 1972, Comanor and Wilson 1974) but it is generally agreed that the higher the level of aggregation, the lower is the elasticity of demand with respect to advertising. Theoretically of course, both expansionary and distributive effects are encompassed in the first order conditions for profit maximisation derived from the economic theory of advertising expenditure determination (Lambin 1976). Even so, the major emphasis in the literature tends to be on the market share effects of advertising expenditures.

1.5.2 New Products, Advertising and Information

However, most of the literature about the relative importance of advertising ignores the distinction between existing products and new products. It seems reasonable to expect that advertising will have a greater role to play in these dynamic circumstances.

2. Acceptance of this view probably results from the underlying belief of classical economists that the economy tends towards full employment equilibrium.

To see this, it must be remembered that mainstream microeconomic theory assumes full information and given consumer preferences. But the introduction of a new product will by definition immediately render existing knowledge incomplete; since consumer preferences for existing products are given, then as new goods appear either these preferences must be altered or a more restrictive initial assumption must be made that preferences are given for all existing and future goods (Lancaster 1966). So, lack of information will be one of the major characteristics of an environment in which new products are being introduced. This gives advertising an important role to play in providing information and establishing consumer preferences for new products.

Potentially then, in a world of product innovations, advertising has a wide role to play and this can raise important questions about its effect on consumer welfare. In the diffusion process (especially the epidemic model), advertising has been nominated a mostly informative role. However no judgement is made regarding the truthfulness and reliability of this information. Whether its presence is increasing or decreasing to consumer welfare and the resulting policy implications are beyond the scope of this thesis.

Of course the effect of advertising may still only be re-distributive in an intertemporal sense, affecting the timing as opposed to the total dynamic demand for the new product. Also, even if one accepts that overall demand for the new product is increased by advertising, the increase in demand may be at the expense of another generic product, with no overall change to aggregate consumption. Such a view would not envisage any significant impact of advertising on aggregate consumption.³

1.5.3 Advertising, Diffusion and the Existing Literature

The number of actual studies that have directly addressed the role of advertising in the diffusion process are few. There are some notable theoretical contributions

³. Duesenberry suggests that new product introductions are responsible for moving the consumption function upwards over time, but once again, empirical evidence at the economy level is contradictory (see Cowling *et al* 1975, Gibbons 1985)

(discussed in the following chapter) recognising the endogeneity of advertising to the diffusion path. However these studies can be criticised for their narrow use of an epidemic demand based model (for short notation this model will be simply referred to as 'epidemic' and is discussed in more detail in the following chapters). Richer, theoretical diffusion models have been derived and applied (for short notation such models will be referred to as 'probit' and are discussed in more detail in the following chapters), but no such model has yet incorporated the role of advertising.

Given the neglect on the theoretical side it is perhaps not surprising that the same state of affairs is reflected in the empirical applications. The writer is not aware of any study in the empirical economics literature which explicitly investigates the significance of advertising in a diffusion model, other than an empirical model developed in Cowling *et al* (1975). This investigation looked at the effect of advertising both on the coffee and tea drinks market as a whole and the substitution of coffee for tea over the period 1960-68.

Some examples are available from marketing researchers, however in addition to their narrow use of an epidemic equation and their failure to incorporate a supply side, such studies generally suffer from their use of relatively unsophisticated statistical techniques, keeping diagnostic testing (if done at all) to its bare minimum. Consequently the robustness of the findings, especially with regard to the size and significance of the advertising coefficient must be called into question. At best their results are tentative, merely hinting at a positive role for advertising in the diffusion of new consumer durables and further rigorous investigation is required before any definite conclusions can be reached.

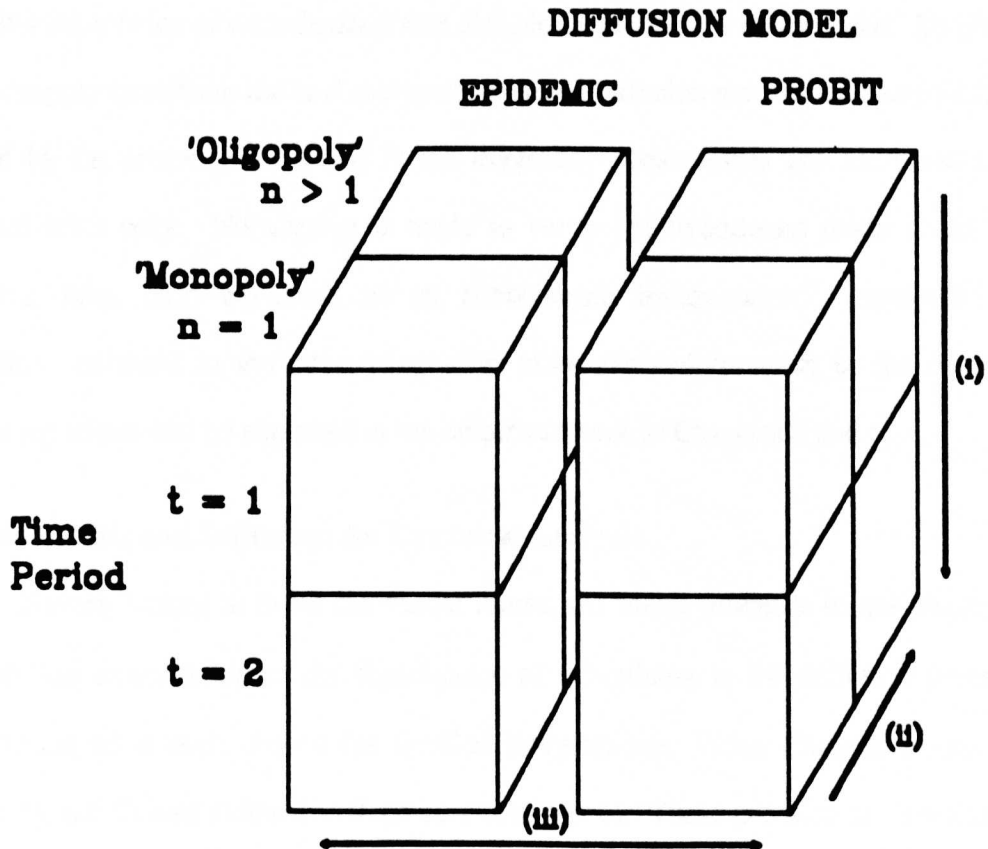
1.6 RESEARCH OBJECTIVES

1.6.1 Advertising and Diffusion; A Theoretical Analysis

The aim of this study is to rectify these deficiencies by focusing explicitly upon the part played by advertising in the diffusion of new consumer durables, both at a

theoretical and empirical level. After reviewing the current literature in Chapter 2, advertising will be incorporated into each of the competing demand side diffusion models, becoming endogenous once a supply side is added (Chapters 3 and 4). For simplicity in the theoretical sections, models with only two periods are analysed. This has the advantage of clearly indicating the dynamic implications in period 1, without the added complications of a fully dynamic model. If the model is interpreted in terms of 'today and tomorrow', then what is of interest is the today results given there is always a tomorrow. Hence the first period results can be viewed as a simple approximation to those that would obtain from a fully dynamic model. This interpretation is used to shift from two period theoretical models to multi period econometric analysis.

The analytical approach adopted in Chapters 3 and 4 is shown diagrammatically below:-



Within each diffusion model the resulting profit maximising advertising sales ratios over time are compared and contrasted with the standard Dorfman-Steiner (1954) and Nerlove-Arrow (1962) expressions found in the industrial economics literature. This comparison over time within each diffusion model is indicated by the arrow labelled (i) in the diagram above.

Alternative supply structures (defined in terms of number of firms) are considered and the resulting effects on the advertising sales ratios within each demand framework are explored. Thus within each demand diffusion framework, the effect of moving from a monopoly to oligopoly supply structure is analysed, as indicated by the arrow labelled (ii) in the diagram. Previously in the literature, the effect of concentration on the advertising sales ratio has been considered but not explicitly for new products in a dynamic framework (Cable 1972, Comanor and Wilson 1974).

Finally, holding the supply structure constant, the different implications for the advertising sales ratios of each demand side diffusion equation are investigated. So given the same supply conditions the two competing demand diffusion models are compared, as indicated by the arrow labelled (iii) in the diagram. These issues are addressed at a theoretical level only. No attempt is made to verify the hypotheses made about the advertising sales ratio equations in an econometric investigation. However the information contained in the advertising sales ratios derived for each of the demand diffusion equations will be exploited in the empirical work in Chapters 5 and 6.

1.6.2 Advertising and Diffusion; An Empirical Analysis

Having looked at these theoretical issues, the thesis proceeds to the empirical validation and examination of the significance of advertising in the diffusion process. Two products have been chosen for detailed investigation, Video Cassette Recorders (Chapter 5), and Colour Television Receivers (Chapter 6). These products are interesting for a number of reasons. The nature of these product innovations is very different and this may have implications for the relative suitability of the competing demand diffusion models used. Colour tv receivers are a good example of an incremental innovation, ie. a

superior substitute product compared to the existing monochrome technology.⁴ On the other hand, the introduction of the video cassette recorder presents a special case of a product for which no close substitute (inferior or otherwise) previously existed, ie, a radically new product (and of course, it is a complementary product to the colour tv receiver). For this latter good, the importance of information may dominate, consequently a model in which the spread of information is the essential feature (eg the epidemic framework) may be more applicable. The choice of the colour tv receiver is interesting because the existing empirical literature contains some evidence of the diffusion process for the television receiver (although mostly confined to the monochrome technology and ignoring advertising) thus enabling some comparison of results. Finally, both products meet an obviously essential criteria for empirical work, namely, an adequate data set could be assembled.

Initially, the standard approach in the literature towards advertising in the diffusion process (ie. integrating advertising into an epidemic demand based diffusion model) will be repeated, to see whether or not the positive results found by previous researchers hold when the econometric model is subjected to a more thorough and intensive diagnostic testing procedure. Given the lack of economic rationale underlying the epidemic specification, it is unlikely that the resulting empirical model will prove statistically reliable. Consequently an alternative empirical model will be established, derived from the richer probit theoretical base, in the expectation of superior econometric results.

The estimation stages in Chapters 5 and 6 call upon the theoretical demand diffusion models presented in Chapters 3 and 4. Observations for the diffusion process will obviously be the combined outcome of demand and supply factors. Supply factors are given limited prominence in the empirical chapters, primarily due to data restrictions. Some attempt is made to correct the estimated structural demand diffusion equations for

⁴. Of course a new product may be introduced for which there is no general agreement on its relative superiority to the existing technology. The question of vertical and horizontal differentiation is considered in Chapter 2.

possible simultaneous equation bias arising from the endogeneity of the advertising variable. The advertising decision equations derived in Chapters 3 and 4 will provide information about the appropriate variables to include in the Two Stage Least Squares estimation procedures. Whilst the explicit consideration of the supply side equations (in terms of the advertising decision variable) themselves would also be valuable, in view of the relative lack of existing empirical research on advertising in the diffusion process, estimation of the structural demand diffusion equations is still worthwhile within itself.

CHAPTER 2

LITERATURE SURVEY

2.1 NEW PRODUCTS AND ECONOMICS

2.1.1 Introduction

Product innovation and the role of advertising in it, whilst receiving scant attention from economists, has been subject to relatively greater enquiry by other social scientists, notably in the management literature (discussed below). However the ultimate objective of their investigations tends to be different (being primarily to forecast sales of the new product) than those of the economist. Thus it is important that economists apply their particular tools of analysis to the subject and witness the resulting outcomes.

Recognition that the economy is in a state of a continual process of change can cause problems for economists. This can be demonstrated most clearly in the economic approach to new products, with them being either ignored or analysed using a framework dominated by orthodox demand theory, which relies upon consumers having full information and given preferences. The traditional analytical framework has proved a very powerful and useful tool in economics. However, in many cases the framework has been derived given the twin assumptions of full information and constant consumer preferences. These two assumptions must be highly questionable in the real world of continual product innovation.

2.1.2 Differentiation

Product innovation has been largely ignored in economics in comparison to process innovation. Indeed product differentiation, although introduced into the literature by Chamberlain (1933) and Hotelling (1929) has received relatively little attention but recently interest has begun once again to focus on the implications of addressing this issue explicitly (see for example Spence 1976; Dixit and Stiglitz 1977; Salop 1979). Once standard analysis is modified to incorporate non homogeneous products, this opens up the possibility of its application to product innovations which are not radically

different to established goods. Abbott (1955) criticised the preoccupation of orthodox economists with price-output relationships to the detriment of product or quality variation, concluding that product heterogeneity was the norm in modern economies. His quality variation analysis refers broadly to product differentiation between existing goods and new products. He did not explicitly refer to the diffusion of new products but hinted at the subject area when discussing how the incentive to create new products was inherent in the economic system. In his world, advertising plays a mainly informative role about the existence of these new products to the imperfectly informed consumer.

Abbott, like later writers on product differentiation, was concerned with discussing the nature of equilibrium in markets for producers of heterogeneous goods. Thus some classification of the type of possible quality changes is needed for analytical convenience. He distinguishes three types of quality differences, vertical (an upward improvement in quality), horizontal (a sideways movement so that only some individuals will consider it an improvement), and innovational (a forward movement in quality that results in improved or more efficient quality). He only presents more formalised models for horizontal and vertical quality competition and being an equilibrium analysis, ignores the process of product innovation where consumers have limited information. However his analytical product differentiation classifications do contain the origins of the definitions put forward by Shaked and Sutton (1982) which are used in chapter 3. Two distinct products are said to be,

vertically differentiated, if when offered at the same price, all consumers would choose the same one, which is then defined as the higher quality one.

horizontally differentiated, if when offered at the same price, each product would have a strictly positive market share.

In the literature, separate models have been developed for vertical and horizontal product competition, although recently some attempt has been made to present

models which integrate both horizontal and vertical differentiated products (Ireland; 1985).

It will be argued that these product differentiation classification are of some applicability in the following analysis since product innovations do not diffuse in a vacuum. Their relationship to existing products can impinge upon the process of diffusion. Completely new and radically different goods are relatively rare. It is much more likely that a new good is some derivative of an existing one. Consequently, some distinction must be drawn about the degree of differentiation of the new product and the vertical/horizontal distinction may be of some use in this. More recently, Stoneman (1989a and b) has given explicit consideration to the effect of product differentiation on the emerging diffusion path under different supply conditions (as these papers employ a probit based demand diffusion equation, discussion will be reserved until the appropriate section later in this chapter).

2.1.3 New Products and the Existing Literature

Lancaster (1966a & b) presents a formal model of consumer behaviour which can readily take account of product heterogeneity and product innovation. In his framework, a good consists of a bundle of characteristics and consumers have preferences for the combination of these attributes rather than for the good itself. On the whole, new products can be considered to possess the same characteristics as an existing substitute, but in different proportions. In this way, new goods are seen as a variant of an existing product rather than a new good. Of course, radical innovations will still be difficult to incorporate, but as argued above, such products are relatively rare with the majority of new products performing functions similar to those of existing goods. Examples will include monochrome and colour television receivers, microwave and conventional ovens and so on.

In this 'New Approach to Consumer Theory', characteristics are seen as intrinsic and objective properties of consumption activities. Each consumption activity is defined by its input (ie. unit of the good) and by the vector of characteristics which forms its

output. Lancaster assumes that psychological aspects such as a consumers relative interest in the different characteristics make their appearance in the preference ordering of the characteristics vectors and not in the relationship between the goods and characteristics.¹ The set of all possible consumption activities forms the consumption technology, which relates the goods to the characteristics. Thus a new product merely adds a new activity to the consumption technology. Like Abbott, Lancaster then views the function of advertising as informing individuals about the existence of a product and the characteristics embodied in it (or maybe price) but this is the full extent to which diffusion of new products and advertising are mentioned.

Ironmonger's (1972) primary concern is with new products and he recognises that goods can have several uses since they are capable of satisfying many wants. Consumers evaluate the want satisfying powers of a commodity which are partly determined by the objective characteristics of the commodity and partly by the consumer's subjective evaluation of its characteristics. Consumers are initially ignorant of the characteristics. Diffusion proceeds as individuals re-evaluate the want satisfying powers of the new commodity. This re-evaluation takes place because consumers are gaining knowledge of the characteristics of the new product either directly by advertising or indirectly through display or usage or by individual contact with a user.

Ironmonger sees this upward revision of consumer estimates of the good's want satisfying powers as the major determinant of growth, although recognising that falling relative prices and rising real incomes also stimulate growth but considering these as relatively incidental to the process. Ironmonger suggests that the successive re-evaluation of the want satisfying powers of the new commodity can be modelled by the simple epidemic equation (described in the next section). Although he mentions advertising as one of the factors underlying the diffusion process, he does not explicitly include it in his theoretical model. Neither does he include this variable in his empirical analysis, which

¹. This contrasts with the model presented by Ironmonger 1972 and implies a different route by which advertising can enter the framework.

consists of the simple linear regression of annual consumption per head of various products on their lagged consumption, price and income.

The work of Abbott (1955), Lancaster (1966) and Ironmonger (1972) makes it clear that new products can cause serious conceptual difficulties for the economist. Their work shows some of the attempts that have been made to overcome the problems and some hints as to the role of advertising in a world of product innovation have been provided. These hints were confirmed to some extent in the empirical model of per capita coffee consumption developed in Cowling *et al* (1975), although the statistical results were not totally satisfactory due to technical problems encountered. However, only when the diffusion process itself becomes the focus of attention, will it be possible to pursue a much wider role for advertising.

2.2 THE DIFFUSION PROCESS; THE EPIDEMIC MODEL

It quickly becomes obvious that the study of the diffusion process is not unique to the economics literature. Researchers from disciplines as diverse as anthropology, medicine and marketing have found the area of interest, applying it to phenomena such as the spread of water boiling in Peruvian villages, the use of new drugs and the ownership of a new product (Rogers 1962).

Even within the narrow confines of the economics literature the amount of work undertaken on diffusion is vast. It is not intended to provide a complete survey of the material. A thorough account of the theoretical developments from an economist's view is provided by Stoneman (1985). Only those theoretical developments relevant to the establishment of the models presented in chapters 3 and 4 are reviewed.²

² For example, given the concentration in this thesis on consumer durables, the game theoretic approach of Reinganum 1981 is not relevant as it abstracts from differences between individuals and diffusion emerges as a consequence of strategic behaviour.

Also, in this thesis a great deal of emphasis is given to the empirical validation of the role and significance of advertising in diffusion models, so more attention will be directed to past literature where estimation has been undertaken. Due to the subject matter of the investigation, studies undertaken by marketing researchers will need special consideration and so a separate section devoted to this literature has been included in this chapter.

Although crossing many fields, an underlying common factor to much of the diverse literature on diffusion has been the employment of a simple mathematical model used by medical scientists to explain the spread of a contagious disease. This epidemic model is often used as theoretical justification for the underlying behaviour (especially in the management and early economics literature) so it is worthwhile exploring this framework in more detail at the outset. The model can be simply expressed by the following equation:-

$$X_t - X_{t-1} = \beta.(X_{t-1}/N).(N - X_{t-1}) \quad 2.1$$

where

X_t = the number of individuals having contracted the infectious disease in time t

N = the number of individuals in the fixed population

β = the social contact coefficient

t = time

If the period $t-1$ to t is very small then this equation can be written as,

$$\delta X_t / \delta t = \beta.(X_t/N).(N - X_t) \quad 2.1a$$

and the solution to this differential equation results in a logistic time curve:-

$$X_t/N = (1 + \exp(-\alpha - \beta.t))^{-1}$$

2.2

where α is a constant of integration and one of the main features of this logistic time curve is its symmetrical S shape.

The basic hypothesis underlying this process is that the contagious disease is spread through the population as infected individuals come into contact with those individuals yet to contract the disease. By using this analogy to explain the spread of use/ownership of a new process or product the term infected individual is replaced by adopter or owner and hence the diffusion model becomes operational.³

However as pointed out by Davies (1979) the simplicity and analytical convenience of the model has often led to its indiscriminate use. The strict underlying assumptions to equation 2.1 are often inappropriate to the behavioural situation being modelled. Also the consequent properties of the resulting logistic diffusion curve may not actually be borne out by the data, thus casting doubt on the suitability of the implicit underlying assumptions of the model.⁴

2.2.1 Implicit Underlying Assumptions

One of the questionable fundamental assumptions to equation 2.1, is that of a homogeneous population with a constant and equal propensity to adopt the innovation as a result of social contact with an existing user. Not only may this contact coefficient be variable over time (see Glaister 1974 for a theoretical extension or Williams 1972 for an empirical example) but also the population N may be segmented such that each sub group varies in its response to the social contact.

3. Strictly the process will never commence unless there exists at least one owner at the outset.

4. Evidence that product innovations do not follow a simple logistic growth path is given by Bain (1962), (1963) who finds a positively skewed distribution preferable in the case of TV in the UK. Also Dixon (1982) in an update of work by Griliches on hybrid corn, demonstrates that the assumption of a symmetric logistic growth curve is inappropriate for about 2/3 of the data set.

Bain (1963) considers that β may in fact vary across social groups, consequently a symmetric logistic aggregate growth curve would not be applicable. Instead the growth path will consist of a series of segments of cumulative lognormal curves where the parameters depend upon social and economic variables. Using data on monochrome TV ownership in the UK, grouped according to social class, household size and geographical region Bain investigates whether or not the parameters of the growth curve vary with respect to these classifications. He finds that the speed of growth parameter does vary considerably such that the smaller the household size and the lower the social class the slower the growth.

The method of using a sigmoid trend curve to summarise the data, where the estimated parameters become the dependent variables explained in a second cross section stage by economic factors, has often been adopted in the economics literature. Usually no attempt is made to justify why a particular trend curve is more appropriate than others, hence the long running dispute concerning the merits of a symmetric or skewed mathematical specification. Mansfield's (1968) investigation of the diffusion of innovations in an industry is a classic example, except he arrives at the logistic growth equation after much mathematical manipulation and assumption. Both the theoretical content and empirical nature of his work has been extensively criticised (for example see Davies 1979).

An earlier example of the approach is Griliches (1957) work on explaining the spread of hybrid corn between geographical regions in the US. He begins by using a logistic curve to summarise the data, generating for each geographical region 3 parameters; the origin (date of first use), slope (rate of acceptance), and ceiling or asymptote (long run equilibrium use) of the logistic curve. The author admits that the choice of a logistic function is rather arbitrary but argues that it is merely used on grounds of simplicity and convenience. The estimated parameters are then explained primarily in terms of profit variables. Commonly in the literature the ceiling parameter is assumed unity, so eventually the entire population will adopt the innovation. However Griliches

chooses the ultimate proportion by visual inspection such that the best logistic curve is obtained.⁵ Differences in the ceiling parameter of the geographical regions are then explained by the profitability variables. The standard of the empirics is simple (which is not surprising given the year) and the work has since been updated by Dixon (1982) using more sophisticated econometric estimating techniques.

The original paper is important as it draws attention to the importance of economic variables (even if limited to profitability). Also, this is one of the earliest papers that mentions, even if only in passing, a role for advertising, asserting that the advertising activities of the seed companies could affect the rate of acceptance parameter in the diffusion curve. However due to data availability the author was unable to empirically validate this hypothesis.

Unfortunately the work still leaves unanswered the explanation of the shape of the trend curve. Indeed in a reply to Dixon, the author (Griliches 1980) reiterates that in no way is the chosen form a representation of an underlying law of diffusion behaviour. It is interesting that in his discussion about the ceiling parameter, Griliches considers it to be variable over time but because of statistical difficulties has to ignore the question of adjustment towards a shifting equilibrium value. Later, in a reply to Dixon, he again questions the validity of using a model with a constant ceiling parameter, especially given the improved state of the econometric art.

In fact, Bain (1962) in his investigation of mono television receiver ownership in the UK incorporates economic variables to explain the ultimate ownership proportion of the population. Specifically the variables included are hire purchase restrictions, average income levels and the availability of ITV. However he continues to use the simple epidemic equation to represent the influence of social emulation. Thus by allowing the ceiling to be endogenous and shifting over time as the economic variables altered, so the growth path consists of a series of segments of logistic curves. His

⁵. Effectively the data is being forced to fit the logistic curve.

analysis suggested that the availability of ITV and changes in credit restrictions had considerable positive and negative effects respectively on the ultimate level of TV ownership. However the income variable did not perform well and in some instances a perverse relationship was found for the availability of ITV variable. Also, a price variable had to be excluded at an early stage as a result of statistical problems.

This paper by Bain is of particular interest due to its specific focus on a new consumer durable (and is referred to again in Chapter 6 when the results for colour television ownership are presented). The extent of formal diagnostic testing in the paper is limited, however the author notes that the precise magnitudes of the estimates need to be treated with caution, given some of the statistical problems encountered. Moreover, the hypothesized logistic curve did not appear adequate at the extremes of the growth process. The model basically being derived from an epidemic equation, is also open to the above noted criticisms of the underlying behavioural foundations inherent in the framework.

The poor statistical performance of the income term and failure to include a price variable would seem to cast doubt on the basic structure chosen. Surprisingly, given the use of a consumer durable, no attention is directed towards advertising. It could have been included as one of the explanatory variables describing the ownership ceiling. Presumably, this omission was due to the belief, as already mentioned, that advertising has a relatively minor role to play on total market demand.

2.2.2 Stock Adjustment Models

The growth curve postulated by Bain looks very similar to that derived from a stock adjustment model, although he did not specifically refer to this concept. Chow (1967) begins directly with such an equation in explaining the growth of computer ownership in the US. He justifies the adjustment process with the usual epidemic reasoning of lags in learning about the innovation. This endogenous adjustment can be

modelled in both levels and logarithmic transformations, thereby resulting in a logistic⁶ or Gompertz specification.

Chow prefers the Gompertz formulation for two *a priori* reasons. Firstly, citing the work of Bain (1964) as justification, a non symmetric growth curve appeared more appropriate (although as Chow is investigating a very different type of innovation any such assumption must be tenuous) and secondly on grounds of analytical convenience. Consequently the shape of the growth curve is not fully explained although Chow does allow for an endogenous and shifting ceiling with the quality adjusted relative price and GNP variables used to explain the equilibrium stock.

Initially Chow uses the price variable solely and obtains a negative and statistically significant coefficient at the 5% level. The author concludes that the Durbin Watson statistic indicates no serial correlation but unfortunately this diagnostic test is not appropriate given the existence of a lagged dependent variable on the right hand side of the equation. This is potentially serious because if serial correlation is present, then the estimated coefficient will be biased and inconsistent.

Chow then re-estimates the equation including GNP as one of the explanatory variables. However the variable did not perform well and resulted in an insignificant and smaller (in absolute terms) price coefficient. In fact most of the explanatory power seems to be coming from the lagged dependent variable.⁷ Chow puts this down to multicollinearity of the explanatory variables and using the estimated relationship from the coefficients on price and GNP, transforms the equation and re-estimates subject to this restriction. The magnitude (in absolute terms) of the price variable is reduced and is only just statistically significant at the 5% level. No further diagnostic testing of the specification is undertaken yet the author concludes that the Gompertz stock adjustment equation with a moving equilibrium level dependent on price can explain the rate of growth of computers in the US. Given the reservations expressed regarding the potential

6. It is not strictly equivalent, see Stoneman (1983).

7. The same results are obtained in the empirical models described in Chapter 5 and 6 of this thesis.

consequences of serial correlation in the statistical model and the obvious sensitivity of the estimated parameters, the magnitude and significance of the effects of the economic variables must be treated with some caution.

Extra evidence of the need for caution is provided by Stoneman (1976), who adopting a similar approach to Chow, investigates the growth of computers in the UK. The statistical results are disappointing and once again it is the lagged dependent variable which seems to be of most significance. Various refinements are made to the basic variables to ensure that the actual measurement more closely proxy the theoretical variables required by the underlying behavioural hypothesis. This includes modifying the adjustment parameter to be dependent upon relevant economic variables (eg growth in output, profits, costs). Unfortunately increasing the sophistication of the estimating equation in this way did not produce better results.

The work of both Chow (1967) and Stoneman (1976) is not specifically aimed at product innovations used by household consumers. However the stock adjustment model has been used by economists to estimate market demand for consumer durables rather than the diffusion curve of a new product *per se*. For example Stone and Rowe (1957) used this type of specification in the estimation of US family consumption expenditure on household durables. Such a variable is very aggregative and will include expenditures on replacement and multiple purchases. The theoretical model employed by the authors accounted for replacement demand and so is consistent with the data used. The equilibrium desired stock is explained in terms of income and price variables, advertising expenditures are not considered.

Williams (1972) uses a stock adjustment equation to model the growth of new consumer durables in the UK. The long run equilibrium level of stock is hypothesised to be a function of price and income (he neglects the possible influence of advertising). The adjustment parameter is positively related to the stock of the durable currently in existence, justified on the usual epidemic grounds that knowledge of the new good is

gained through contact with existing owners. So his basic estimating equation is as follows,

$$S_t - S_{t-1} = (\phi + \delta S_{t-1})(S_t^* - S_{t-1}) \quad 2.3$$

$$S_t^* = f(\text{price, income}) \quad 2.4$$

S_t^* = long run equilibrium stock of a new consumer durable at t

S_{t-1} = stock of consumer durable at the end of period t-1

The constant ϕ is included in the adjustment function to allow for the possibility of a positively skewed growth process.⁸

Williams then adds richness to the model by allowing the parameter δ to be subject to short term fluctuations such as alterations or expectation of alterations in purchase tax, hire purchase regulation, changes in consumer attitude and seasonal variation, all of which obviously affect the timing of the purchase decision. In the empirical investigation, applied to television receivers and refrigerators, changes in consumer attitudes are proxied by the rate of change of income, whereas the problem of measuring expectations on the other variables is effectively ignored with current levels of the relevant variables themselves used.

The resulting equation is complex, containing non linear restrictions, so a maximum likelihood estimation procedure is used. The results for the television growth equation will be considered in more detail in Chapter 6. Generally the econometric results are mixed. The performance of the parameters in the desired stock equation was better than that of the short run fluctuation parameters in the adjustment function. This latter function was in fact dominated by the existing stock variable (like previous writers and the results presented in Chapter 5 and 6) with the hire purchase term being the only

8. In this form if S_t^* is assumed constant, the equation is observationally similar to that of Lekvall and Wahlbin (1973) or Bass (1969) (both described later), although the underlying behavioural explanation differs. Williams does not use the epidemic model interpretation explicitly, only vaguely implying this sort of behaviour in justifying the inclusion of S_{t-1} in the adjustment function.

short term variable to affect significantly the rate of adjustment for TV receivers but conversely being the only short term influence not to be significant for refrigerators.

This is a very interesting application of the stock adjustment model to the growth of consumer durable ownership with more richness added to the basic equation due to a variable adjustment function. However, in so doing, the final estimating equation becomes very complex. Moreover some doubt must be cast upon the correctness of the specification for a likelihood ratio test of the non linear restrictions was substantially rejected.

Autocorrelation was found to be a problem and the model was transformed to account for first order serial correlation only. Autocorrelation could in fact be an indication of a mis-specified model and simply transforming the equation might not really be appropriate. Also as quarterly data is being used, investigating higher order serial correlation might be more pertinent. Finally no attention was given to the possibility of including advertising in the model either in explaining the equilibrium desired stock or as a factor affecting the timing of the purchase decision.

2.2.3 Diffusion, Information and Advertising

The simple epidemic behavioural process has proved very popular in describing the spread of ownership or use of an innovation, either through the use of the simple epidemic equation itself or when used indirectly to rationalise the existence of the lagged stock variable in the adjustment function of a stock adjustment model.

However, as pointed out by Stoneman (1985), the epidemic model is really describing the transmission of information and should therefore account for forms of information transfer other than by social contact, the most obvious other form being advertising. Lekvall and Wahlbin (1973) recognised this by interpreting the behavioural nature of the simple epidemic model in terms of an external and internal influence on the

communication of information on an innovation. Their work is entirely theoretical with no empirical investigation.

They argue that the shape of the diffusion curve for a new product is primarily a function of the nature of the process of communication about the innovation among prospective adopters, the two major forms of influence on the individual adoption process being external and internal. The distinction depends upon whether the source emanates from outside the set of prospective adopters or from members of the social system respectively. As an example of the external channel of information transfer, Lekvall and Wahlbin quote advertising, whereas the internal channel refers to social interaction or 'word of mouth' and the demonstration effect (where mere usage or consumption of some good will communicate information and influence individual attitudes towards it). A simple epidemic model is employed with a one stage adoption process so that once a non adopter receives information, he immediately becomes an adopter. So,

$$\frac{\delta y}{\delta t} = \frac{[N-y] \cdot [g+ky]}{N}$$

2.5

where,

N = number of prospective adopters.

g = number of individuals contacted through external influence such as advertising.

k = number of influential contacts made by adopters.

y = number of adopters of the innovation.

The authors go on to show how the shape of the diffusion curve will depend upon the relative strength of the external channel of information. When $g = 0$, then the simple epidemic model results and so the curve is logistic. At the other extreme when $k = 0$ the curve is a modified exponential.

This paper is useful in emphasising that it is the spread of information which is analogous to the contagious disease epidemic equation and showing how advertising can have an important role to play. However the role of advertising is not developed in any great detail at the theoretical level and no empirical work is undertaken. Being basically an epidemic model it suffers from the criticisms already mentioned (such as a homogeneous population, one stage adoption process etc). Also the model is not totally correct as presumably the marginal buyer can receive information from both the internal and external channels simultaneously. Strictly one needs to argue that the mathematical equation 2.5 is in fact a linear approximation.

Another major problem of the model is its total concentration on demand side factors. Advertising is seen as influencing the shape of the diffusion curve and yet the role of suppliers and their advertising policies are not pursued. Explicit recognition of the importance of both demand and supply side factors on the resulting shape of the diffusion curve was clearly demonstrated by Stoneman and Ireland (1983). As the demand framework used by these authors is very different to the epidemic model, discussion of their model will be reserved for later in the chapter. However it is worth pointing out that supply side factors had not been totally ignored by previous writers. Griliches (1957) mentions that the growth curve observed was an intersection of short run supply and demand curves. He overcomes this problem by assuming that the supply curve of the innovation being investigated is very elastic, such that demand factors dominate. Also other writers have incorporated supply factors, if in a limited way, into their models. In particular there are two papers which address advertising in this context.

Gould (1970) stresses the notion that it takes time for information to spread through a market and that diffusion models are primarily reflecting this phenomenon. He uses two basic models developed by Stigler (1961) and Ozga (1960) respectively. Essentially, these frameworks are similar to the internal and external channels of influence presented by Lekvall and Wahlbin (1973), except that the two sources are not combined into one equation. Instead Gould analyses each model separately. The Stigler

based model is like the external channel of influence process with the addition of a constant forgetting parameter in the equation. Advertising acts upon the direct contact coefficient (represented by g in the Lekvall and Wahlbin equation 2.5 above). The other model based upon the framework presented by Ozga is primarily a simple epidemic equation where information is spread by social contact. In addition some of the existing information is forgotten in each period at a constant rate. The role of advertising promotions in this framework is to increase the social contact coefficient (equivalent to k in equation 2.5 above) but unlike the Stigler model, advertising does not have a direct effect.

Gould then separately analyses the profit maximising advertising policies for a monopolist in each of these information diffusion models. Not surprisingly, the qualitative properties of the optimal time path of advertising differ with the demand diffusion process employed. In the Stigler model, the optimum policy is to advertise most heavily at the start of the campaign and continually decrease these expenditures to the long run equilibrium level. In the second model adapted from Ozga, the time path will generally be quite different. At the beginning the profit maximising level of advertising will be low, it then builds up to a maximum which lies above the equilibrium level, and finally reduces towards this level. Gould incorporates a simple supply side into the diffusion model and highlights the differing role and policy implications but he only considers the case of a profit maximising monopolist. Because the models are not referring explicitly to product diffusion but to information spread, no attention is paid to other economic variables except for a note in the conclusion that 'there certainly will be shifts in the demand function over time'. Also of course the work is theoretical and no empirical investigation is undertaken.

Glaister (1974) also incorporates supply side factors into a diffusion model by concentrating upon a monopolist's profit maximising price and advertising policies. The underlying behavioural model is one where information flows between individuals and like Lekvall and Wahlbin, once a member of the potential market receives the information

he automatically becomes a buyer of the new product. Glaister arbitrarily restricts the primary role of advertising to be indirect, increasing the initial number of users who then act as impartial information carriers in the social contact transmission process. This word of mouth advertising provides the extra stimulus required before a potential buyer is transformed into an actual buyer.

Basically, Glaister adopts a simple epidemic equation and allows some owners to forget or become passive in the information transfer process at a given rate. He then obtains a threshold effect such that the initial number of potential buyers must exceed the ratio of the rate of loss of users (as they forget or become passive) to the social contact rate, if sales are to 'take off'. This condition will be independent of the initial number of owners who can be created by advertising. However once the threshold is crossed, the number of initial owners at the start of the process becomes more important and consequently so do advertising expenditures. It is therefore imperative that the seller carefully selects the subpopulation of identical individuals who are the potential buyers of the new product if this threshold condition is to be met.

Interestingly, Glaister suggests that advertising could have a role in increasing the density of potential buyers but does not further continue this line of thinking.⁹ Also he informally discusses the possibility of competitors advertising affecting the rate of loss coefficient but keeps it constant in his model since he refers solely to a monopolist supplier. Price is incorporated into his model indirectly through the social contact coefficient and he interprets his modified epidemic equation as the probability of purchase given that information about the innovation has been received.

Due to mathematical complexities, Glaister initially ignores advertising and looks at the profit maximising time path of price. He concludes that under certain special assumptions (constant marginal cost of production, constant price elasticity and constant elasticity of the threshold condition, ratio of loss of users to social contact coefficient), it

⁹ The size of the market or population would then be a function of economic variables, in this case advertising.

is optimal for the monopolist to have a cheap introductory offer price below marginal cost for this increases the successful contact rate, which in turn affects the skewness of the growth curve, prompting earlier sales than otherwise.¹⁰

He then investigates the profit maximising advertising strategy during a launching campaign, assuming price is held constant at its long run monopoly equilibrium level. Not surprisingly, the advice is to adopt heavy advertising expenditures in the early period falling away to zero at the point of complete market penetration. This encourages the early growth of users who will then act as information carriers.

Glaister does not attempt to incorporate a wider role for advertising, its effects being predominantly secondary in nature and no empirical investigation is undertaken. However it is a further example, although limited, of the consideration of supply side factors in the diffusion process, in particular including advertising.

Before turning to the development of alternative demand diffusion models which have a richer microeconomic base, it is necessary to consider diffusion models presented in the marketing literature as the issue of advertising has been more directly addressed (certainly at an empirical level). It is appropriate to take this slight detour now because on the whole, the demand diffusion models employed are observationally equivalent to the epidemic model already discussed.

2.3 NEW PRODUCT DIFFUSION IN THE MANAGEMENT LITERATURE

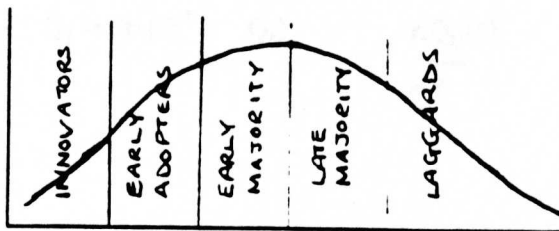
2.3.1 Introduction

It is not surprising, given their interests, that diffusion of new products has been investigated in the management literature and obviously some attention has been paid to the role of advertising here. Generally, the main concern of writers in this field is to produce a model that can forecast the future sales of a new good. Consequently less focus is given to deriving a theoretically sound model and establishing statistically

¹⁰. This is often referred to as penetration pricing strategy in the marketing literature.

significant parameters. Instead the data is used to fit the most suitable mathematical model in order to forecast future sales of the product.

In terms of its theoretical base, reference is made to the model proposed by Rogers (1962). Individuals are assumed to differ in their response to a new idea and their 'innovativeness' can be classified as in the diagram below,



time
Source: Rogers 1962

Given this behaviour, the firm can then target its promotional efforts towards the group of innovators. Of course this begs the question, who are the innovators? Rogers and Stamfield (1968) looked at a large number of research studies and found that among other things, social characteristics such as income and standard of living correlated with the identification of innovators. From an economist's point of view, this would be expected.

2.3.2 Innovators vs Imitators

However when moving to the modelling stage, much of the potential behavioural content of the work of Rogers is lost for the specification is simplified to such an extent that only two social categories remain, innovators and imitators. Little if anything is said about their different characteristics, indeed models are used which implicitly assume a homogeneous population (this conflict is dealt with in more detail later on). For diffusion to proceed over time (as is observed in practice), there must be some mechanism to prompt purchase by early adopters and so on down to the laggards. Personal influence and social contact are assumed to play an integral part in this process.

The innovators act as opinion leaders and communicate with the imitators. By using epidemic diffusion models, this social interaction is summarised.

2.3.3 The Bass Equation

The earliest formalisation of this approach is by Bass (1969). He generates an expression that is similar to an epidemic equation written in discrete form as follows,

$$Q_{t+1} - Q_t = p.(Q^* - Q_t) + \frac{r.Q_t.(Q^* - Q_t)}{Q^*} \quad 2.6$$

where,

Q_t = cumulative unit sales at time t

Q^* = total potential market

p = coefficient of innovation

r = coefficient of imitation

Using annual time series data on unit sales for eleven consumer durables in the US, Bass derives the structural parameters p , r , Q^* from the OLS estimates. The objective is to obtain a good forecasting model, consequently the standard of diagnostic testing is very primitive, mostly relying on R^2 . Given that this model uses a lagged dependent variable as the basic explanatory variable, it is not surprising that high values of R^2 are obtained. If in addition the data suffers from serial correlation, the estimates will be biased and inconsistent. Interestingly, the author notes that where deviations from the forecast trend are noticeable, this coincides with short term income variation. This hints that the model may benefit from the inclusion of economic variables in explaining the diffusion process.

A major criticism of the Bass equation as pointed out by Tanny and Derzko (1988), is that the mathematical model does not reflect the underlying behavioural

interaction of innovators and imitators. As they say, 'whether an individual ultimately adopts the product as a result of this tendency to innovate or through contact with an adopter is a process affecting all individuals in the same way'. The writers are surprised that this logical contradiction appears to have gone unnoticed in the management literature, emphasising that Mahajan and Peterson (1985) even omitted the basic population homogeneity assumption from the list of assumptions underlying the fundamental diffusion model!

Of course as the writers point out, this inconsistency does not invalidate the research conducted to date which uses this model, rather it is a question of the misinterpretation of the parameters p and r in the Bass model. Provided that users of this model are aware that the mathematical specification merely distinguishes between adopters and non adopters then it is still adequate. As has already been seen, Lekvall and Wahlbin interpret these two coefficients as reflecting different sources of information rather than due to differences in the nature of individuals in the population.

Tanny and Derzko go on to derive a model which more accurately reflects the innovator-imitator dichotomy. This involves individually modelling the two population sub groups with the innovator sub group responding to an external source of information only, such as advertising (although this is not explicitly incorporated in the specification). The second sub group describing the imitators, respond primarily to information gained from social contact with adopters in both groups as well as some external information. The writers proceed to empirically estimate by Non Linear Least Squares (NLS) the sales curve, which comprises the sum of the individual sales curves of the innovators and imitator sub group.

The authors obtain very disappointing results but are aware of the data limitations of using at most 12 to 14 annual observations to estimate 5 parameters. Also the raw data is itself subject to much measurement error, for example including repeat and multiple purchases. In some cases, they found that estimation of the simple Bass

equation actually produces better results (measured in terms of mean square error (MSE) and mean absolute deviation (MAD) only). Given the data inferiority coupled with the use of a sophisticated estimation technique, it is surprising that the authors expect the data to distinguish the innovator-imitator dichotomy and it is much more likely that a simple model would seem to be more statistically robust (although, even this conclusion should be treated prudently as the range of the diagnostic testing is not extensive).

2.3.4 Modifications to the Bass Model

Despite its skimpy theoretical base and major shortcomings, the Bass model has proved very popular in the management literature and is normally employed as the fundamental equation. However the weaknesses have not been ignored and more recently, various attempts have been made to modify some of the more artificial assumptions underlying its specification. Of particular interest are those examples which have sought to incorporate advertising and these will be discussed in more detail below. However it is worth briefly mentioning some of the other main areas of improvement. The interested reader is referred to Mahajan and Muller (1979) or Mahajan and Wind (1986) for a more detailed account of the diffusion model in the management literature.

2.3.4.1 A Non Constant Population

In the Bass equation, the number of potential adopters or population is assumed constant over the entire diffusion process and hence its numerical value is derived from the estimated parameter. If the time span of the process is of considerable length this would appear to be a dubious assumption. The potential population of adopters is likely to change at least as a result of demographic factors such as the number of households, or alternatively the ceiling can be determined by economic factors such as price or income.¹¹

¹¹ This alternative view places a different interpretation on the model and it no longer describes a disequilibrium process. This is dealt with in more detail in the next chapter.

Mahajan and Peterson (1978) replace the constant ceiling assumption with a dynamic one. Simply, they assume the population of potential adopters at a point in time is a function of relevant exogenous or endogenous factors. Employing data on washing machine sales in the US¹² and United Nations membership, the authors use the size of the relevant demographic population for the explanatory variable in the potential population equation. Thus the number of housing starts in the US is used for washing machines and number of countries in the world for UN membership.

Over time these demographic variables are likely to grow and using annual observations and a basic epidemic structure to represent the growth equation, the interpolated values are used in the estimation of the potential population, which is hypothesised to be a simple linear function of the demographic population. So the potential population becomes dynamic and can be substituted into the basic diffusion equation which explains the transfer of an individual from the potential market into an adopter by social contact. Thus their final estimating equation becomes,

$$\ln Q_{t+1} - \ln Q_t = B_1 + B_2 H_t + B_3 Q_t$$

$$\text{and } B_1 = bk_1, \quad B_2 = bk_2, \quad B_3 = -b \quad 2.7$$

where,

b = the coefficient of internal communication or imitation

Q_t^* = cumulative potential population at time t and

$$Q_t^* = k_1 + k_2 H_t$$

Q_t = cumulative adopters at time t

H_t = relevant demographic population at time t

¹². The authors do not explicitly state whether this data refers to units and has been adjusted for repeat and replacement purchases.

With a maximum of 30 annual observations the structural parameters are derived from the coefficients estimated using OLS. The authors do not report the standard errors of regression coefficients but state that they are all statistically significant at the 1% level, with the exception of the social contact coefficient B_3 in the washing machine equation. The authors conclude that the model, using a dynamic potential population performs better relative to the simple Bass model.

Unfortunately no substantial diagnostic tests are performed and so the specification of the model cannot be challenged. Unlike writers in the economics field such as Chow(1967), Mahajan and Peters do not attempt to include economic variables in Q^*_t , instead assuming that the potential population is a constant linear function of a relevant demographic variable. In the empirical chapters below, the potential population is also taken to be the relevant demographic population, however actual observations, rather than a linear function of them, are incorporated into the epidemic framework.

2.3.4.2 Awareness and Adoption

Another problem with the basic Bass equation (and epidemic model) is its simplistic binary approach to the adoption decision. Potential adopters in the population either adopt or do not. Once individuals come into contact with an existing owner, their purchase decision is automatic.¹³ Dodson and Muller (1978) attempt to add richness to the decision process by including 3 stages in the adoption process, unaware, aware and purchase. This results in a modification to the Bass equation by disaggregating the non adopter population into those individuals who are unaware of the product and those who are aware but have chosen not to purchase to date.

¹³. As will be argued in the next chapter, the automatic transmission from non adopter to adopter once information about the new product is received, does seriously limit the situations in which the epidemic model is applicable.

Individuals become aware either by social contact with those individuals already informed (this will include owners and non owners)¹⁴ or from an external source which could include advertising. A constant proportion of informed individuals become actual owners and the writers suggest that a firm's promotional activities could affect this rate, although this is not explicitly modelled. They also extend the model to allow for repeat purchases with some individuals forgetting previous information received.

Effectively Dodson and Muller are establishing a generalised version of the Bass model which incorporates slightly more realistic assumptions with respect to the decision process. They show how using particular restrictions on the parameters, earlier models such as those proposed by Bass (1969), Gould (1970), Glaister (1974) and Nerlove and Arrow (1962) deduce from their generalised model or at least are closely related.

Whilst having the advantage of being relatively more realistic than the Bass model or epidemic equation, the biggest drawback to the resulting generalised equation is its non operationality. Unless data is available on the numbers in the population who are unaware or aware but not yet owners at each point in time, the general model cannot be applied empirically. Also, assuming that a constant proportion of the informed individuals automatically become owners, does not overcome the weaknesses of the decision theoretic base of the Bass model.

2.3.4.3 Marketing Variables in the Bass Model

Not surprisingly, writers in the management field have sought to incorporate marketing variables into the Bass equation. Those models which focus upon price will be briefly mentioned before turning to the marketing variable of most interest in this investigation, namely advertising. Mahajan and Peterson in the model described above, did refer to price as one of the factors affecting the potential population, however they did

¹⁴ It is assumed that these individuals despite being non purchasers, nonetheless pass on positive information.

not pursue this theme either theoretically or empirically. Robinson and Lakhani (1975) allow price to enter into the Bass equation in a multiplicative fashion. The population of potential adopters is assumed constant but price affects the rate of adoption through the 'imitation' coefficient.¹⁵ The writers go on to discuss the profit maximising strategy along the diffusion path but do not give any empirical validation of their model.

A slightly different way of introducing price into the diffusion equation is presented by Bass (1980). Interestingly, this paper also models the price setting behaviour of the supplier and so explicitly incorporates a supply side into the diffusion process. He argues that as a result of learning economies, costs fall in relation to cumulative output. The myopic monopolist supplier maximising current output sets marginal revenue equal to marginal costs. Thus prices are also declining over time. Demand depends upon price (which in turn is a function of cumulative output as described) and is multiplied by an exogenous time variable representing an exogenous shift in demand (Bass suggests this time shift factor to be the curve generated by his original simple model in equation 2.6 above).

Bass empirically tests his model for 6 consumer durables. The actual estimating equation is in reduced form, however the structural parameters are identified by a two stage process, initially obtaining estimates of the constant learning parameter in the price equation. Then assuming the elasticity of demand is constant, the parameters can be derived from the estimated reduced form coefficients. There are problems both logically (since as Stoneman (1983) points out, his theoretical model assumes a monopolist supplier whereas this industry structure does not hold within the data used) and econometrically because the extent of the diagnostic testing is almost non-existent. Therefore the robustness of the specification cannot be confirmed. The author himself admits that on his own criteria (*a priori* expectations of the magnitude of the parameters), the equation is likely to be mis-specified for two of the products.

¹⁵ Like Glaister where $\beta = f(\text{price})$.

Kalish (1985) proposes a model that incorporates both price and advertising. His theoretical framework also benefits from a sounder economic decision base. There are two stages in the decision process, individuals become aware and then choose whether to adopt the innovation. The awareness stage refers to information about search attributes¹⁶ and this sort of information is spread by advertising and word of mouth contact modelled in a simple epidemic framework, (but in which, a distinction is made between existing owners and members of the population who are aware but not yet owners, like Dodson and Muller). The adoption stage is conditional upon being aware and occurs if the perceived risk adjusted reservation price exceeds the product selling price. Individuals differ with respect to their true underlying reservation price but are equally risk averse. Perceived risk exists due to uncertainty about the experience attributes of the new product but is reduced as the number of actual owners increases. The adoption stage is modelled as a stock adjustment equation with a constant adjustment parameter. The desired stock or potential population depends upon the proportion of the population who are aware of the product multiplied by the risk adjusted price (where the risk adjustment depends upon the existing penetration level of ownership). This is obviously an improvement on the model presented by Dodson and Muller for the author does not assume that a constant proportion of aware individuals adopt, but explains this in terms of risk adjusted price.

Kalish also discusses the profit maximising price and advertising policies of a monopolist. Costs are assumed to be a function of cumulative production and the optimum price path is monotonically decreasing over time, unless the effectiveness of adopters in generating awareness and or the uncertainty reduction from early adopters is high. The profit maximising time path of advertising is monotonically decreasing over time, assuming decreasing returns to scale in advertising and a zero discount rate. These results extend to the case when the discount rate r is positive, so long as r is not 'too big'.

¹⁶ Following Nelson (1974), the author assumes that search attributes are those characteristics which can be verified before use eg. colour weight size, whereas experience attributes such as durability and reliability will only be revealed by using the product.

At introduction, provided $r < b$ (where b represents the effectiveness with which actual adopters transmit information) then the result will hold.

When turning to the empirical investigation stage much of the theoretical richness is abandoned. The author has the same problem as Dodson and Muller; without information on the level of knowledge in the non adopter population, the awareness equation cannot be estimated. He therefore restricts his attention to the adopter (stock adjustment) equation, assuming the proportion of the population aware to be unity. The potential market or desired stock functional form is imposed with price and existing proportion of owners as the explanatory variables.

The structural parameters are estimated using NLS on 32 quarterly observations for a consumer durable (no information is given about the product). Very little attention is directed towards establishing the robustness of the estimated coefficients. The model is judged on its forecasting ability relative to alternative specifications in the management literature such as those of Robinson and Lakhani⁽¹⁹⁷⁵⁾ or Mahajan and Peterson⁽¹⁹⁷⁸⁾. The price and population parameters are extremely sensitive to the model specification employed, hence emphasising the need for a thorough investigation of the statistical robustness of each model before any conclusions can be reached.

2.3.4.4 Advertising in the Bass Model

Turning now to the marketing variable of primary interest, it is clear that some of the papers already discussed do refer to advertising but not in any explicit or thorough manner. Horsky and Simon (1983) directly model advertising in the Bass equation and proceed to test the validity of their model empirically. For them, the primary role of advertising is to inform the innovators directly about the existence and value of the new product. The imitators are not affected by this external source of information and instead rely on social contact with existing owners of the new product.

Horsky and Simon employ a model which implicitly assumes a homogeneous population and yet in their discussion of the innovator-imitator dichotomy, they refer to differences in the characteristics of these sub groups. For example, the innovators are assumed to obtain a greater utility from early ownership relative to the imitators and are not as risk averse, so consequently do not need the information reinforced from an impartial source (existing owners). The logical inconsistency of the interpretation of the underlying behavioural nature of the actual mathematical model employed still applies. However the authors argue that their equation could represent the average probability of purchase and so each individual is a mixture of both innovator and imitator, accepting information from all sources.¹⁷

In order to substantiate their model empirically, Horsky and Simon effectively assume that the external or innovator coefficient in the Bass equation is a function of advertising expenditure. The actual form used is,

$$Q_t - Q_{t-1} = [\alpha + \chi \cdot \ln A_t + \beta \cdot Q_{t-1}] \cdot [N - Q_{t-1}] \quad 2.8$$

where

N = the number of potential buyers in the population

Q_{t-1} = the number of individuals who have already adopted at time $t-1$

A_t = the level of advertising expenditure by a monopolist at time t

α = information conveyed to innovators through alternative means such as press reports

χ = the effectiveness of advertising directed towards the innovators

β = the effectiveness of word of mouth information

¹⁷. This is analogous to the 'linear approximation' argument used to justify the epidemic model presented in chapter 3.

So a diminishing marginal effectiveness of advertising is imposed *a priori*, since the natural log transformation of advertising expenditures is used and no alternative forms considered. A maximum of 26 monthly observations on the number of new telephone banking accounts opened with a bank in a geographical region were used to estimate by NLS the time series equation 2.8 above. This exercise is repeated for a total of 5 localities. The estimated parameters for the effectiveness of advertising and word of mouth were positive and statistically significant at the 5% level in all regions.

Unfortunately, very little diagnostic testing of the model is performed. Given that monthly data is being used, it is likely that serial correlation could be present and coupled with a lagged dependent variable on the RHS of the equation, the estimates will be biased and inconsistent. The description of the data is fairly brief so it is not clear whether advertising expenditures are in nominal or real terms. Nominal values will fail to capture the real volume of messages, resulting in measurement error in one of the explanatory variables. This causes the estimated parameters to be biased and inconsistent.

The authors also investigate the optimal advertising policy for a monopolist in their model. The analytical solution as a function of time is judged to be too difficult and so the characteristics of the optimal advertising policy are discussed. Assuming a constant price cost margin over time and that $\beta N > r$ (where r is the cost of capital), generates optimal advertising to be a decreasing function over time. Thus the profit maximising behaviour for a monopolist is to advertise heavily in the initial period to inform the innovators and gradually reduce such promotions as these individuals act as word of mouth carriers.¹⁸

A paper by Simon and Sebastian (1987) addresses some of the empirical shortcomings of the Horsky and Simon model. They too use the basic Bass equation but set up 6 econometric specifications based upon different assumptions about the

¹⁸. Advertising is seen as indirectly having a lagged effect via these word of mouth carriers only, no additional goodwill effects are included.

parameters influenced by advertising and the lag structure of the advertising effects. The objective is to evaluate empirically the alternative models using data on the diffusion of new telephones in West Germany. However the authors qualify this objective with the statement,

'it is naive to assume that we can discriminate between the alternative models on purely econometric grounds. We will have to appeal to behavioural and situational considerations.'

The competing specifications allow for advertising to enter through the innovation coefficient or the imitation coefficient. A third possibility which combines both, proved intractable econometrically giving several wrong parameter signs and was therefore rejected. Also the possibility that the potential market itself was not constant but a function of economic variables such as advertising was rejected for being behaviourally insignificant and econometrically difficult to measure.

This seems questionable unless the Dodson and Muller model is being followed rigidly so that data on the non adopters at any one time needs to be broken down into those informed and those ignorant of the product. If instead, the primary role of advertising is seen as transferring individuals from the relevant demographic population into the potential market, then an econometric approach similar to that used by Chow could be employed, with advertising as one of the variables explaining the potential population N .

However if in addition, advertising is expected to affect the rate of transfer of individuals from the potential market into actual owners, it is likely that an econometric model would fail to distinguish both routes.¹⁹ Moreover, by letting the potential market be equal to a demographic factor such as number of households,²⁰ the empirical impact

¹⁹. Although Williams (1972) did not use advertising, his model did incorporate economic variables in the adjustment function and potential population function but the results proved unsatisfactory. Stoneman in his investigation of use of computers in the UK found similar problems.

²⁰. As is done by Simon and Sebastian (1987) and the procedure followed in the later empirical chapters of this investigation.

of advertising is blurred and the advertising variable may be picking up the combined effect of advertising on transferring a member of the population into the potential market and into an actual user. It is therefore not feasible to argue that the effect of advertising has been segregated into the final stage only, as implied by Simon and Sebastian.

Given the two competing specifications,

MODEL 1

$$Q_t - Q_{t-1} = \phi + [\alpha_0 + \alpha_{1t} + \beta \cdot (Q_{t-1}/N)] \cdot [N - Q_{t-1}] \quad 2.9$$

where

α_{1t} is the effectiveness of information conveyed to innovators and is a function of advertising expenditures by firms, ie $\alpha_{1t} = f(A_t)$

N = the number of potential buyers in the population

Q_{t-1} = the number of individuals who have already adopted at time $t-1$

A_t = the level of advertising expenditure by a monopolist at time t

β = the effectiveness of word of mouth information

MODEL 2

$$Q_t - Q_{t-1} = f + [\alpha + \beta_t \cdot (Q_{t-1}/N)] \cdot [N - Q_{t-1}] \quad 2.10$$

where

β_t = the effectiveness of word of mouth information and is affected by advertising such that,

$$\beta_t = b_0 + b_{1t} \text{ and } b_{1t} = f(A_t)$$

The authors also discuss the lag structure of the advertising variable. Like Horsky and Simon (1983), they impose *a priori* a natural log transformation but they also

allow for current sales to be affected by past advertising efforts directly, not just through word of mouth carriers. Two basic lag hypotheses are used,

STRUCTURE A

$$f_t(A) = \sum_{i=0} \theta_i \ln A_{t-i} \quad 2.11$$

and

STRUCTURE B

$$f_t(A) = \theta \ln G_t \quad 2.12$$

where G_t is a stock of goodwill such that

$$G_t = \sum_{i=0} w_i \ln A_{t-i}$$

The weights w_i in the stock of goodwill are assumed to have a beta distribution, the parameters of which are found by a search procedure once this function has been substituted into the basic diffusion model.

As mentioned earlier, the writers are not convinced that the innovator vs imitator role for advertising is merely an empirical matter. They argue that it depends upon factors such as the stage of the product life cycle. At the beginning advertising is primarily directed at the innovators and later on at the imitators. Presumably this could be tested empirically by looking at the stability of the respective estimated coefficient over time, provided that the data covered the full length of the product life cycle. Unfortunately as the authors investigate a period at the start of which 49% of the population are already owners, this possibility would not be open to them.

As the writers use monthly data, a 12 lag model is used to test the dynamic effect of advertising. Not surprisingly, only one of the lags in Structure A is significant and as they say, this is most likely due to multicollinearity of the advertising lag variables. However no joint test of significance seems to have been performed.

The authors conclude that the stock of goodwill specification proved superior in both the innovator and imitator models. Both specifications gave adjusted R^2 of approximately 0.8 but much of this explanatory power could be due to the dummy variables which are included to account for seasonality and telephone rate structure changes.

The diagnostic testing of the models rests upon adjusted R^2 , t statistics and predictive performance measures and on this basis coupled with their *a priori* expectations, the imitation model with a stock of goodwill (model 2B) is favoured. The possibility of autocorrelation is not addressed and this would seem to be a distinct possibility given the use of monthly data. Bearing this in mind, advertising is found to have a small positive and statistically significant effect in accelerating the diffusion process for telephone installations. The average goodwill elasticity was calculated to be approximately 1.16% but varied considerably over time. Also the lag structure indicated that advertising attained its maximum effect with a delay of about one half year with 72% of the total advertising effects occurring between 4 - 9 months.²¹

The Simon and Sebastian paper is one of the few attempts to validate empirically the effectiveness of advertising in the diffusion process. The example product chosen did generate certain data advantages. For example 91 monthly observations for a product supplied solely by one firm, during which time the product itself did not alter to any major degree (this must be very rare). Also, whereas installation data were available as an explanatory variable in the equation, monthly applications data were available as the dependent variable. This enabled the authors more accurately to reflect demand conditions, ruling out supply factors such as shortages etc which might blur the data.

However the data had some disadvantages because presumably the problem of repeat purchases and replacement demand will remain in the data and conflict with the

²¹. It is interesting that in the empirical investigations in chapters 5 and 6, although using different products, the lagged effects of advertising seem to dissipate after 9 months.

underlying behavioural model which applies to first use only. Unfortunately the data refers to both the household and corporate sector. The authors assume that all existing companies have a telephone so that any new applications from the corporate sector will be from newly formed companies. On this basis, they include a constant term in the model to account for this demand. This assumption would appear unrealistic given that the data set covers 10 years. Also it seems likely that nominal advertising expenditures were used rather than real volumes.

The results certainly indicate a role for advertising in the diffusion process, if somewhat minor, through either the innovator/external channel coefficient (Horsky and Simon) or the imitation/internal source of information coefficient (Simon and Sebastian). However in order to increase confidence in this conclusion and in the magnitude of the estimated parameters, the robustness of the models should be subject to more rigorous diagnostic testing.

So far the few empirical studies that have looked at the role of advertising in the diffusion process have found positive results. However Kalish and Lilien (1986) conclude that advertising is insignificant in their model. They estimate a diffusion curve for a new consumer durable²² incorporating both price and advertising. In effect, the estimated model is a stock adjustment equation, with the desired stock being equal to a relevant demographic population, weighted by the fraction of this population who find the product acceptable and this fraction depends upon price.

The adjustment parameter is not assumed constant (this is obviously similar to Williams (1972), although he does not include advertising), but is a function of word of mouth and advertising information sources. The form in which these variables enter into the adjustment parameter is imposed *a priori* to be,

$$f(ADV, WOM) = \frac{c + a.ADV + b.WOM}{1 + a.ADV + b.WOM}$$

²². Very little information is given about the data, on the grounds that it is proprietary in nature.

and the variables also enter in an imposed manner,

$$ADV = 0.5.A_t + \sum_{i=8} A_{t-i}.0.6^i \quad 2.14$$

where A_t = Advertising expenditures in time t .

$$WOM = \sum_{i=8} sales_{t-i}.0.8^i \quad 2.15$$

The equation, subject to these many arbitrary assumptions, is estimated by NLS using quarterly data. The authors note that all the parameters except e and a are statistically significant. So they conclude that advertising is not very effective in the diffusion equation. No formal diagnostic testing is undertaken except to note the DW statistic of 2.05 indicates that serial correlation is not a problem.

Unfortunately, given the use of a lagged dependent variable as one of the explanatory variables, this statistic would be biased towards 2 in the event of autocorrelation and in any case is not really applicable given the use of NLS. As quarterly data is being used, it would seem advisable to investigate the presence of higher order serial correlation. Many restrictions are imposed *a priori* without any statistical test of their validity. On the whole this research would appear naive and inferior to the other empirical papers of Horsky and Simon (1983) and Simon and Sebastian (1987).

2.4 THE DIFFUSION PROCESS; PROBIT MODELS

As can be seen, the epidemic based diffusion model (or Bass equation) has proved a very popular vehicle in the diffusion literature, moreover some attempt has been made to incorporate advertising into the model, although in a limited and empirically unsatisfactory manner. But the epidemic model from an economist's point of view, suffers from a fundamental weakness, it has no economic decision theoretic base.

2.4.1 Threshold/Probit Approach

Alternative models have been developed which contain a richer micro economic foundation, the objective being to explain the resulting aggregate diffusion curve in terms of economic variables. These models, often referred to as threshold or probit models begin with the notion that individuals in the population of size M differ with respect to some characteristic Z_i ($i=1....M$) and therefore start from a very different perspective from the epidemic model. Given some assumption about the distribution of Z over i , then at any point in time an individual will adopt the innovation if Z_i exceeds a critical level Z^* , hence the concept of a threshold which has to be crossed before an individual adopts the innovation. By defining the appropriate characteristic and its distribution, the determination of the critical value and how this critical value varies in relation to the distribution of the characteristic over time, the emerging diffusion path is fully explained.

Such a model differs from an epidemic framework not only in respect of the underlying economic behaviour, but also in regard to the interpretation of the concept of equilibrium. The epidemic model primarily shows a transition towards a long run equilibrium level, consequently the diffusion process is one of disequilibrium adjustment towards a constant ceiling.²³ In contrast, these threshold or probit models describe an equilibrium process because at each point in time, all those wishing to adopt, have done so. There will be no further forces causing adjustment unless the equilibrium position itself alters.²⁴

David (1969) gives an interesting application of this approach to the introduction of the mechanical reaper in the US. Adoption will take place only if labour savings from the use of the innovation exceeds its cost. The potential for labour savings will differ amongst the population due to differences in the size of the potential adopters farm. So the critical value of farm size will be determined by the relative input prices (wages and annual cost of reaper) and the labour savings of the new technology relative

²³. Except in those extensions which explicitly model the ceiling as a function of economic variables and so is changing over time.

²⁴. The differing concept of equilibrium is discussed in more detail in the next chapter.

to the old. As either this relationship changes over time or the distribution of farm sizes shifts, so the diffusion path will be described. David assuming a given lognormal distribution for farm sizes, then imposes an exogenous constant growth in relative wages and so obtains a sigmoid diffusion curve. The diffusion process is thus basically being driven by an exogenous factor.

The model developed by Davies (1979) is very similar but more realistic, as it allows uncertainty to enter into the decision process. Firms are considered satisficers rather than profit maximisers and consequently the notion of payoff periods is employed. An individual firm will adopt the new process provided that the expected time taken for the innovation to recoup the initial outlay exceeds some acceptable payoff period. The expected payoff period is assumed to be a function of firm size and other unspecified firm attributes. The acceptable pay off period is also a function of firm size and other unspecified firm characteristics.

Davies then argues that over time, the expected pay off period will decline due to improvements in the technology (as a result of supplier's learning economies) and better information received by potential adopters, which in turn, leads to improved expectations. Davies distinguishes two classes of innovations, Group A innovations which are reasonably cheap and simple, and Group B innovations which are complex and expensive. He then argues that the rate of decline in the expected payoff will vary between these two classes. He also considers that the acceptable target pay off period will be relaxed over time but that this rate of decline will also vary between Group A and B innovations.

From these hypotheses, the author predicts a cumulative log normal time path for the diffusion of Group A innovations and a cumulative normal time path for Group B innovations. An empirical investigation is undertaken and the hypothesised models appear consistent with the data giving inferior results when the 'wrong' theoretical curve

is applied to the data. Davies then proceeds to use the estimated diffusion speed parameters as dependent variables in a second cross section estimation stage.

The contributions of David and Davies are significant due to the superior economic rationale underlying the diffusion equation. However they are limited because they concentrate on the demand side factors only, consequently appeal must be made to exogenous changes in order to drive the diffusion process. Also, neither David or Davies explicitly model the problem of limited information which could prevent instantaneous adjustment to the equilibrium position (although Davies does implicitly use the idea that increasing information over time is justification for falling expected payoff and target payoff periods). It seems reasonable to argue that if the lack of information does constrain the diffusion process, then it would be most acute in the early stages of the process.

2.4.2 Probit Models and Supply Factors

As already shown, the importance of supply side factors on the diffusion path has not been totally neglected in the literature on epidemic models. However the demand side of such models does not benefit from the richer theoretical reasoning of the probit framework, relying instead on an epidemic specification. This shortcoming is overcome by Stoneman and Ireland (1983), who integrate a supply side with the probit type demand diffusion model of David (1969) and Davies (1979). Unlike these authors, the model presented by Stoneman and Ireland endogenises the price path which drives the diffusion process. This results from modelling the supply sector ie. the behaviour of producers of the new technology.²⁵ Their demand framework is used as the foundation to the model presented in more detail in Chapter 4, however whilst Stoneman and Ireland concentrate upon endogenous price decisions driving the process, interest in that chapter is directed towards advertising expenditures as the relevant supply side variable. Changes in the level of quality of the new product after its introduction are not considered in this thesis.

²⁵. Strictly this applies only in the case of a monopolist supplier. When the model is extended to an oligopoly situation it is exogenous factors in the shape of assumed increasing user wage that drives the process.

However, in a recent paper, Stoneman (1989a) confronts this issue directly. A monopolist supplier chooses both price and quality and diffusion proceeds as price falls or quality improves over time. Also in this thesis, intra product heterogeneity of the new product is ignored but Stoneman (1989b) considers the implications of differing supply conditions on the diffusion path when there are a number of different brands of the new generic product. Given myopia on the part of consumers, when a monopolist supplier offers a number of brands of the new generic product, diffusion is faster the greater is the number of brands offered. For an oligopolistic industry where each brand is controlled by a separate firm, each oligopolist acts like a single brand monopolist with a monopoly price. Thus the diffusion path is unaffected for a period until in some period there is an end period competitive game which will drive usage above the monopoly level.

2.4.3 Consumer Durables and Probit Models

Given that the focus of attention is the diffusion of process innovations, it is not surprising that advertising is not considered a variable worthy of investigation by David (1969), Davies (1979) *et al.* However the use of a threshold or probit concept has been used by previous writers in the economic literature in explaining the factors affecting the ownership of major consumer durables (Farrell (1954), Cramer (1962)). However these studies are not concerned explicitly with new products or the diffusion process itself. A cross sectional approach is adopted to explain ownership of existing durables as a function of the characteristics of owners at one point in time. It is not until changes over time in the stimulus variable (usually income in these studies) and or the critical value distribution are explained that a diffusion path emerges. Dernberg (1958) also uses a threshold argument in his cross sectional study of the determinants of ownership of a new product, namely TV, by families in the US in 1950. A time path emerges because the author allows the threshold index to be partly determined by the period for which a TV service has been available.

Bonus (1973) provides a very interesting empirical application of this probit approach and because he has both cross section and time series data²⁶ on various new consumer durables for households in West Germany over the period 1956-67, he is able to estimate Quasi Engel curves. These show the probability of ownership for a given level of income at a given point in time and consequently is in effect the cumulative distribution of critical values. The author can then statistically examine the hypothesised linearity (due to the assumed distributions) of the Quasi Engel curve and the stability of the parameters over time. As the structural parameters of the distributions can be deduced from the estimated parameters, any changes in them over time will lead to various conclusions on the reasons for growth in ownership of the products investigated. For example, growth in ownership of cameras and projectors is found to be fully income induced since the distribution of critical values is stable over time, the fraction of the population who are potential owners is unity throughout, but the distribution of actual incomes shifts over time. In the case of TV everything is changing, with shifts in the critical and actual income distributions and a changing fraction of potential owners in the population over the period studied.

The aggregate diffusion curve is found by aggregating the Quasi Engel curves over the income distribution at each point in time. Given the assumed lognormal distributions and various additional assumptions on the time path of the parameters (the means and variances of the actual and critical distributions and the fraction of potential owners in the population), Bonus shows how a variety of aggregate diffusion curve shapes can result. Contrary to other writers, he finds a symmetric logistic curve emerges as a result of changes in actual income only and not because of epidemic learning.

The use of a superior data set enables Bonus, using a more satisfying economic decision foundation, to separate the epidemic learning effects from the economic variables (in this case income) and to go some way towards explaining the shape of the diffusion path for various new consumer durables. However the problem still remains

²⁶. Not panel data.

that changes in the fraction of the population who are potential owners and shifts in the critical value distribution are imposed rather than explained.

It would seem that other economic variables such as price and especially advertising could have a valuable role to play in explaining changes in these parameters. Also at this stage incorporation of a supply side so that changes in these decision variables might drive the process would be appropriate. Unfortunately data requirements are likely to limit the possibility of following through the investigation of the effects of advertising using a combined cross section time series approach.

2.5 THE INTEGRATION OF EPIDEMIC AND PROBIT MODELS

It is interesting to note that Bonus, by using a simple logistic function of time to describe how the fraction of potential owners in the population increases, does attempt if somewhat implicitly, to integrate the epidemic and probit models.

This objective is approached more directly by David and Stoneman (1986) who use a probit based framework to model the fully informed adoption decision and this is weighted by the fraction of the population who are aware of the innovation. Individuals in the population become aware through epidemic learning and from an exogenous source. The authors do not attempt to validate their model empirically, the work being entirely theoretical, the aim being to investigate the welfare implications of government policy towards information dissemination or subsidy under different supply conditions.

Whilst their integration approach is more theoretically satisfying, Bonus (1973), by summarising the information transmission process with an assumed logistic curve opens up the possibility of empirical application. However this approximation then makes the role of advertising in the process itself unreceptive to direct empirical validation.

2.6 SUMMARY

From the literature, there have been basically two competing demand diffusion frameworks employed to explain the diffusion of new consumer durables, the epidemic and the probit models.

The epidemic model has been extended to incorporate a role for advertising. Also at a theoretical level, this framework has been used to take account of the endogeneity of advertising decisions assuming a single monopoly supplier of the new product. Some limited empirical testing of the role and significance of advertising in an epidemic based demand diffusion equation has been undertaken. On the whole, the robustness of the resulting econometric specification is open to question, given the limited and simple diagnostic testing of these models.

Whilst a probit framework has been used to model the diffusion of a new consumer durable (based on demand factors only), no consideration has been given to the role of advertising in such a model, either at a theoretical or empirical level.

Each of these competing demand diffusion specifications has a very different underlying behavioural foundation. The reasoning behind the epidemic model makes sense in explaining the spread of information about the new product, that is, the awareness stage. The probit model is more applicable to the adoption stage, assuming full information. In reality diffusion of a new product is the outcome of both the awareness and adoption stage, consequently there has been an attempt to integrate both models. However the focus of such work is theoretical with no attention given to the inclusion of advertising in the integrated model.

Unfortunately, at an empirical level, a combined approach will prove extremely difficult to validate, especially if the intention is to include additional economic variables (such as advertising) into the explanation of the information dissemination process. The resulting estimation equation will prove complex and messy and it will be asking a lot of the data to distinguish the route by which the economic variables have entered.

Consequently the following chapters will maintain the separation of the two competing demand diffusion models. This will have the advantage of highlighting the special features of advertising in each framework and the consequences of a changing supply structure, without blurring the analysis. Also at an empirical level, it will enable comparison and validation of previous work, which has been confined to the integration of advertising in an epidemic model.

CHAPTER 3

THE ROLE OF ADVERTISING IN AN EPIDEMIC BASED MODEL

3.1 INTRODUCTION

In this particular chapter, one of the competing demand diffusion models (the epidemic framework), will be discussed. The prime purpose is to incorporate advertising expenditures. Like Lekvall and Wahlbin, the epidemic model will be interpreted in terms of information diffusion, and advertising expenditures will constitute an additional and external source of information flow. Having discussed the main theme of such a model, a supply side is then considered.

To begin with, the analysis centres on a single supplier of the new consumer durable. The advertising sales ratios derived from the first order conditions for profit maximisation within this model are investigated over time, and compared and contrasted with the standard Dorfman-Steiner and Nerlove-Arrow conditions found in the literature.

Having done this, the monopolist supplier assumption will be relaxed. Again the profit maximising advertising sales ratios will be derived and the outcome for these ratios of using a dynamic framework for new products will be considered. Finally, the effect of a changing market structure (in terms of number of suppliers) on the profit maximising advertising sales ratio in the epidemic model is explored. The implications of relaxing the Cournot behavioural assumption are discussed informally.

3.2 FRAMEWORK OF ANALYSIS; SOME GENERAL ISSUES

Before proceeding to the theoretical analysis of the epidemic model, it is useful to clarify certain assumptions and conceptual issues used in this chapter.

3.2.1 Diffusion vs Demand Theory

The focus of this thesis is on new product introduction at the industry level. The analysis centres upon the generic product and is not concerned with either explicitly

investigating the diffusion of a particular standard of the product (eg VHS versus Betamax video cassette recorder) or a particular variant or 'brand' of the generic product.

Another distinction in the analysis must be emphasised. Diffusion theory, when applied to a new consumer product, is concerned with the initial spread of ownership of this product, ie the cumulative proportion of the population who become owners/users over time. Whilst diffusion proper will include both the initial use and extent of use, this work is primarily concerned with the decision to adopt for the first time. To use an analogy from capital theory, interest here centres upon product widening, not product deepening. So by assumption, multiple product ownership is not being analysed. Whilst this may be realistic for certain consumer durables, where usually only one unit will be acquired, such as washing machines, it is by no means always appropriate. However as this analysis concentrates on the early period of the product life cycle, it is probably a reasonable assumption.

This does not exclude the feasibility of modifying diffusion models to incorporate such features, if so desired (Mansfield 1968 or Glaister 1974). Similarly, replacement expenditure is assumed here to be of no importance. Once again there are specific examples where such assumptions have been relaxed (eg. Dodson and Muller, 1978). However since here the models are being applied to consumer durables and the emphasis is on first use, on the grounds of simplicity this added complication was not introduced into the analysis. With most consumer durables, it is unlikely that replacement purchases will be very significant over the periods in the product life cycle prior to maturity.

3.2.2 Population Definition

The epidemic diffusion model uses a satiation concept for the proportion of the population who eventually become owners ie. X_t^* / N . Normally this proportion is assumed to be unity. However at any point in time the number of owners ie. X_t is not equal to X_t^* . Thus X_t approaches X_t^* in a disequilibrium process. The rate of adjustment

of X_t to X_t^* can be determined by economic variables (the primary variable of interest in this thesis being advertising), however in its simplest form, the epidemic model needs no economic variables to drive the diffusion process. X_t will eventually approach the saturation ceiling due to information being spread by the social interaction amongst the homogeneous population.

3.3 THE EPIDEMIC MODEL

3.3.1 Advertising, Diffusion and Information

The basic epidemic model is built upon the theory of social contagion. It has been seen that a useful interpretation of this model when applied to economic phenomena, is that it refers to the transmission of information, with a given population of potential owners adopting the new product as they become informed of its existence.

In its simplest form, the model allows for only one source of information, contact with existing owners. To limit the model in this way is obviously unrealistic. Moreover it requires information from an exogenous source at the start of the process. Lekvall and Wahlbin (1973) have shown that extending the basic model to allow for information from an external source such as advertising can overcome this second problem. However even the restricted epidemic model still calls for some suspension of disbelief about realism, especially if a saturation ceiling of unity is imposed. For then, the only constraint on the inevitable purchase decision is lack of information. Once informed, from what ever source, an individual will become an owner of the new durable without further recourse to any economic decision making based on variables such as relative price, or income. This seems highly dubious, nonetheless, it could be argued that such a model will have limited applicability to a particular type of product innovation.

Recall that new products (which are not radically different to existing goods) can be differentiated from similar existing goods and categorised as vertically or horizontally distinct. Vertical differentiation implies that all potential buyers are agreed about the new product's superiority to the existing substitute. So a ceiling of unity (given

appropriate prices) may be a realistic assumption and the use of the epidemic model could be appropriate.

Within the epidemic framework, the function of advertising will be to provide information, both directly as an external source and indirectly by increasing the number of information carriers in future periods. There has been great debate in the literature about whether advertising is informative (eg. Stigler 1961, Telser 1964 and Nelson 1974) or persuasive (eg. Bain 1968, Comanor and Wilson 1974). This conceptual distinction has been criticised for being non operational and thus redundant and there is certainly some justification in this argument. Within the diffusion models, advertising is allocated a primarily informative role. However, advertising could just as likely be informing individuals about the relative price or the image of the new product and the information provided need not be reliable or truthful. No judgement will be made about the value of the information and so the effect on consumer welfare and the resulting policy implications will not be considered.

3.3.2 The Theoretical Model; A Monopolist Supplier

A model will now be established using the epidemic demand diffusion equation with advertising included as a direct external source of information. The profit maximising advertising sales ratios applicable to a monopolist supplier of the new product will be derived and these expressions considered over time and compared to the standard Dorfman-Steiner and Nerlove-Arrow advertising sales ratios.¹

3.3.2.1 Assumptions

For simplicity a two period model labelled 1 and 2 will be employed. Demand is represented by a modified epidemic equation in which advertising enters as a direct external source of information through α_t in the equation (3.1) below:-

¹ This model will be modified in a later section to allow for more than one supplier. The advantage of initially restricting the model to a monopolist supply is that a comparison can be drawn about the effects of these differing supply conditions upon the advertising sales ratio in an epidemic diffusion model.

$$X_t - X_{t-1} = \frac{[\beta \cdot (X_{t-1}) + \alpha_t] \cdot [N - X_{t-1}]}{N}$$

3.1

where

β = the effectiveness of social contact coefficient and $0 \leq \beta \leq 1$

A_t = Advertising messages in time t and $\alpha_t = g(A_t)$.

α_t = the effectiveness of advertising messages coefficient.² $\alpha_t \geq 0$

X_t = cumulative owners at time t and $X_t \leq N$

N = size of population of potential acquirers of the new product.

The monopolist supplier is assumed to maximise discounted profits Π by the choice of his advertising expenditures in each time period given the demand equation 3.1 where,

$$\pi = PX_1 + \frac{P}{1+r}(X_2 - X_1) - C_1X_1 - \frac{C_2}{1+r}(X_2 - X_1) - A_1 - \frac{A_2}{1+r}$$

3.2

where

Π = Discounted profit of a monopolist.

X_1 = Cumulated unit sales in period 1 (since by assumption owners purchase one unit only).

X_2 = Cumulated unit sales in period 2.

therefore

² In order to make this model operational, especially when moving to the estimation stage of the investigation, some functional relationship must be specified. For the moment the function will be left in its general form.

$(X_2 - X_1) =$ Quantity sold in period 2.

$A_t =$ Advertising expenditures in time t .

$C_t =$ Marginal cost in period t (assumed constant).

$P =$ Monopolist price (assumed constant, but see discussion on this point below).

$r =$ Discount rate.

Equation 3.2 can be expanded and rewritten in stock terms as follows;

$$\pi = PX_1 + \frac{P}{1+r}X_2 - \frac{P}{1+r}X_1 - C_1X_1 - \frac{C_2}{1+r}X_2 + \frac{C_2}{1+r}X_1 - A_1 - \frac{A_2}{1+r} \quad 3.2b$$

Constant marginal costs within a period will be assumed but may differ across periods.

The simple epidemic model normally takes N as given. Thus emphasising the rate of approach towards this given level due to the spread of information amongst the homogeneous population. It is arguable that the size of N could be determined by economic variables such as price.³ Diffusion will then consist of both adjustment towards the ceiling of the epidemic equation and shifts in the ceiling itself. As argued in the last chapter, it will then prove extremely difficult to disentangle these effects empirically.

On the other hand, ignoring any such changes in N has the advantage of specifically focusing attention upon the effect of advertising on the rate of approach to this given ceiling. However this is achieved at the expense of implicitly treating another important economic variable price (P) as constant over the two periods. It could be argued that N will be that level determined by the long run equilibrium price for a monopolist. The analysis would then follow the same approach as Glaister (1974), keeping the separation on the grounds of mathematical intractability.

³. In empirical work, Bain (1964) suggested that N could depend upon economic variables such as price. In which case the asymptote of the epidemic equation would be shifting over time towards a saturation of unity.

This is obviously an artificial partition. In reality, a monopolist would use advertising and price simultaneously. Indeed in an epidemic based model, given incomplete knowledge, one could perceive that any reduction in price would need to be accompanied by advertising in order to inform individuals of the price change. Unfortunately, because the epidemic model assumes a homogeneous population, there is little possibility for including price in any satisfactory manner. Rather than include this variable in an *ad hoc* manner, it would be preferable to employ a model using a more satisfying decision-theoretic base, such as the probit model introduced in the next chapter. Indeed the main contention of the empirical investigation to follow, is the *a priori* belief that the epidemic model is too naive to describe the diffusion process adequately. The probit based model is expected to perform better statistically. However given that the few empirical studies to include advertising have mostly used an epidemic framework, the model will still need to be investigated.

In this simple framework, with advertising as the only decision variable, the essence of the determination of advertising expenditures centres upon the profit maximising allocation of information by the monopolist supplier between the two periods and this will affect the timing of demand. Why then would a supplier not wish to ensure that all of this demand arose in the first period? One possibility is that the exogenous price cost margin, ^(assumed constant as explained above) in the second period may be higher. So the benefits of waiting until the second period will be positive. However it may not be rational to meet demand entirely within the second period as the monopolist will also have to take account of the costs of waiting, that is the discount rate r . Thus the profit maximising outcome is likely to lead to a distribution of advertising expenditures across time. Additionally, if no information is supplied from an external source in the first period the diffusion process will not operate unless the assumption is made that at least one owner already exists at the start of the first period. Previously it was noted that the models employed in the marketing literature tend to call these knowledgeable individuals 'innovators' as opposed to the 'imitators' who learn of the new product through 'word of mouth' contact.

3.3.2.2 Paths of Influence of Advertising

The effect of advertising expenditures in the two period epidemic model can be broken down into three paths of influence. Firstly and most directly, advertising in a period is an external source of information and therefore directly increases the number of actual owners in periods 1 and 2. This is the full extent of the influence of advertising in period 2 as this is the final period in the model. However in period 1, the increase in the number of owners has two further indirect effects which work in opposite directions. The new owners become information carriers about the product in the next period⁴. This word of mouth information flow in the next period, represents a positive dynamic information externality and shall be called the information carrier effect.

However, given that N is fixed, as the number of first period owners increases, the number of potential buyers left in the second period obviously decreases. This negative effect on demand shall be referred to as the negative early extraction effect. Whether the sum of these indirect effects of first period advertising and hence the overall dynamic owner externality, is positive or negative, depends upon the relative strengths of these two opposing forces. That is whether or not the benefit of increasing the number of information carriers offsets the cost of early extraction of the owner from the finite population.

To summarise, first period advertising expenditure in this two period epidemic model has an impact through three channels.

1. on current demand through α_1 ; this effect is positive.
2. on second period demand via X_1 ; this dynamic owner externality can be positive or negative as it depends upon the net effect of,
 - i) the positive information carrier effect

⁴ The implicit assumption here is that the information will be positive and will not dissuade a potential owner from becoming an owner. This is reasonable given that the information is by definition of a generic nature and as previously argued, applicable to vertically differentiated goods where agreement on their superiority is accepted by all of the potential population..

ii) the negative early extraction effect.

If the number of actual users at the beginning of a period is relatively large, any additional advertising expenditures in that period could be superfluous, for the existing number of information carriers will already be large relative to the number of non owners left to be transformed into actual owners. In equilibrium, the allocation of advertising over the two periods will be taken to the point where the marginal benefit in terms of discounted profit of transforming the marginal buyer in the first period equals the marginal cost. The benefit will include the dynamic owner effect, ie, the value of the net outcome of the opposing information carrier and early extraction effects.

First Order Conditions for Profit Maximisation

These arguments can be seen more clearly by looking at the first order conditions for the maximisation of discounted profit Π by the choice of advertising A by the monopolist (recall that price is assumed fixed, maybe at the long run monopolist equilibrium level). The derivation of the first order conditions is detailed in Appendix 3.1 at the end of this chapter. In equation 3.3, the first order condition relating to advertising in period 1 is reproduced.

$$\frac{\partial \pi}{\partial A_1} = (P - C_1) \frac{\partial X_1}{\partial A_1} + \frac{(P - C_2)}{1+r} \frac{\partial X_1}{\partial A_1} \left[\frac{\partial X_2}{\partial X_1} - 1 \right] = 0 \quad 3.3$$

The direct net benefit of advertising expenditures in period 1 is represented by the first term on the right hand side of the equation. However there is also an additional term which is the dynamic net benefit, $(P - C_2)/(1+r) \cdot \partial X_1 / \partial A_1 \cdot [\partial X_2 / \partial X_1 - 1]$. It is composed of the discounted marginal contribution in period 2 and the indirect impact and effectiveness of period 1 advertising via X_1 and explicitly includes the dynamic owner externality $[\partial X_2 / \partial X_1 - 1]$.

This indirect dynamic effect need not be positive as already explained. It becomes a question of the sign of $[\partial X_2 / \partial X_1 - 1]$. Referring back to the epidemic equation (3.1), the following can be derived

$$\left(\frac{\partial X_2}{\partial X_1} - 1 \right) = \beta \left[1 - 2 \frac{X_1}{N} \right] - \alpha_2 \quad 3.4$$

The RHS includes the parameters associated with the internal or word of mouth channel of information, β , as well as the external channel of information in period 2, α_2 . If the overall dynamic owner externality is to be positive then,

$$\beta \left[1 - 2 \frac{X_1}{N} \right] - \alpha_2 > 0 \quad 3.5$$

where

$$0 \leq \alpha_1 \leq 1, \quad 0 \leq X_1/N \leq 1, \quad \beta \geq 0$$

If X_1/N is more than 0.5, then condition 3.5 is violated. Effectively this implies that the negative early extraction effect dominates the positive word of mouth or information carrier effect, there already being a relatively large number of information carriers compared to the potential market of non owners remaining in the second period.

If X_1/N is less than 0.5, then whether condition 3.5 holds depends upon the relative magnitude of the information carrier effect and the negative early extraction effect. If the effectiveness of period 2 advertising α_2 is relatively large, this will serve to enhance the negative first period extraction effect. The more effective is period 2 advertising, then *ceteris paribus*, the greater will be the sacrifice resulting from early extraction since the marginal buyer could be left dormant and be extracted later using the relatively effective external channel of current advertising in period 2.

If $\beta[1 - 2X_1/N] > \alpha_2$, then the information carrier effect more than compensates for the full opportunity cost of extracting the marginal buyer in period 1 rather than 2.

If $\beta[1 - 2X_1/N] < \alpha_2$, then the relative effectiveness of period 2 advertising serves to enhance the opportunity cost of extracting the marginal buyer and the information carrier effect is too weak to fully compensate.

3.3.2.4 Advertising Sales Ratio in the Epidemic Model

In the literature, interest in the firm's advertising decision tends to focus upon the advertising sales ratio. The standard profit maximising result known as the Dorfman-Steiner condition shows that

$$A/PX = \eta_a/\eta_p$$

3.6

where

η_a = elasticity of flow demand wrt advertising

η_p = elasticity of flow demand wrt price

The profit maximising advertising sales ratio for a monopolist within the epidemic model in period 1 is derived in appendix 3.1b and reproduced below,

$$\frac{A_1}{PX_1} = \frac{P-C_1}{P} \eta_{q1A1} + \frac{P-C_2}{P(1+r)} \eta_{q1A1} \left[\frac{\partial X_2}{\partial X_1} - 1 \right]$$

3.7

where

$$\eta_{q1A1} = \frac{\partial X_1}{\partial A_1} \frac{\partial A_1}{\partial X_1} \frac{A_1}{X_1}$$

elasticity of flow demand in period 1 wrt advertising in period 1

3.8

The Dorfman-Steiner (D-S) condition which does not take account of any dynamic effects and the ratio in the epidemic model differ due to the final term on the

RHS of equation 3.7 above.⁵ Whether or not the D-S ratio will be larger or smaller depends upon the dynamic owner externality term. As explained above, this ultimately comes down to the relative magnitude of α_1 , α_2 and β .

The profit maximising advertising sales ratio in period 2 for a monopolist in the epidemic model is as follows,

$$\frac{A_2}{P(X_2 - X_1)} = \frac{P - C_2}{P} \eta_{q2A2} \quad 3.9$$

where

$$\eta_{q2A2} = \frac{\partial(X_2 - X_1)}{\partial \alpha_2} \frac{\partial \alpha_2}{\partial A_2} \frac{A_2}{(X_2 - X_1)} \quad 3.10$$

elasticity of flow demand in period 2 wrt period 2 advertising

Not surprisingly, this expression corresponds exactly to the usual D-S condition since by definition period 2 is the final period and hence there are no further dynamic effects to be taken into account.

3.3.2.5 Goodwill Effects of Advertising

In the standard industrial economics literature on advertising, it is common practice to enter advertising into a model via the stock of goodwill. This latter approach has been adopted because it has been argued that the effects of advertising do not fully dissipate within the current period. Advertising expenditures are thus seen as analogous to investment expenditures, adding to a stock of capital, where the capital is called a stock of goodwill. In the epidemic model a dynamic effect has already been generated without recourse to this device. The reasons for including lagged effect of advertising

⁵ As price is not endogenous in this model, the price cost margin has not been substituted for its profit maximising condition $1/\eta_p$ as in the Dorfman Steiner expression.

expenditures in the standard literature have been discussed in Cowling *et al* (1975). However the information carrier effects that arise in the epidemic model have not been used in the standard literature as specific justification for treating advertising expenditures as a stock of goodwill. It can be argued that some of the reasons given by Cowling and others (eg. the durable form in which some expenditures like press advertising occur), still apply in the epidemic model and should be included as an additional dynamic source to that already contained within the epidemic framework (as done by Simon and Sebastian in their empirical model).

When advertising is treated as a stock of goodwill, the standard Nerlove-Arrow (N-A) result for the profit maximising goodwill sales ratio is that in 3.11.⁶

$$\frac{G_1}{P_1 q_1} = - \frac{\eta_{q_1 G_1}}{\eta_{q_1 P_1}} \left(\frac{1+r}{r+2\delta-1} \right)$$

$$\frac{G_2}{P_2 q_2} = - \frac{\eta_{q_2 G_2}}{\eta_{q_2 P_2}}$$

3.11

where

$$G_1 = A_1$$

$$G_2 = A_2 + (1-\delta)A_1$$

$$q_1 = f(G_1, P_1)$$

$$q_2 = f(G_2, P_2)$$

G_t = Stock of goodwill in period t .

A_t = Advertising expenditure in time t .

P_t = Price in period t .

⁶ The Nerlove - Arrow result is not normally presented in a discrete model. However it has been derived here within a two period model in order to aid comparison with this epidemic framework (see Appendix 3.2).

q_t = Flow demand in period t .

r = Rate of discount.

δ = Rate of decay of the stock of goodwill.

$\eta_{q_t G_t}$ = Elasticity of flow demand in period t wrt the stock of goodwill in period t .

$$\eta_{q_1 G_1} = \frac{\partial q_1}{\partial G_1} \frac{G_1}{q_1} \quad , \quad \eta_{q_2 G_2} = \frac{\partial q_2}{\partial G_2} \frac{G_2}{q_2}$$

$\eta_{q_t p_t}$ = Elasticity of flow demand in period t wrt price in period t .

$$\eta_{q_1 p_1} = \frac{\partial q_1}{\partial p_1} \frac{p_1}{q_1} \quad \eta_{q_2 p_2} = \frac{\partial q_2}{\partial p_2} \frac{p_2}{q_2}$$

If advertising has a goodwill effect, this increases the ways in which advertising expenditure in period 1 affects demand in the epidemic model to the following:

- 1 an effect on current demand through α_1 ; this effect is positive.
- 2 an effect on second period demand through X_1 ; this dynamic externality can be positive or negative as it depends upon the net effect of
 - i) the positive information carrier effect
 - ii) the negative early extraction effect
- 3 an effect on second period demand through the impact of goodwill on α_2 ; this goodwill effect is positive and comparable to the Nerlove - Arrow path of influence.

Concentrating upon the first period profit maximising advertising sales ratios (derived in Appendix 3.3), it is clear that the goodwill sales ratio in the epidemic framework 3.12

$$\frac{G_1}{pX_1} = \frac{(P-C_1)}{P} \frac{(1+r)}{(r+2\delta-1)} \eta_{q_1 G_1} + \frac{P-C_2}{P} \left[\frac{\partial X_2}{\partial X_1} - 1 \right] \frac{\eta_{q_1 G_1}}{(r+2\delta-1)} \quad 3.12$$

differs from equation 3.11 by the second term on the RHS of 3.12 which represents the effect of the additional channel of information described in influence 2. If the rate of decay $\delta = 1$, then the goodwill effect is zero and so the epidemic result in equation 3.7 is reproduced. However in general, the profit maximising goodwill sales ratio in the epidemic model will be larger than that suggested by Nerlove and Arrow provided that the two following conditions hold,

$$1) \left(\frac{\partial X_2}{\partial X_1} - 1 \right) > 0 \quad 3.13$$

$$2) 2\delta > 1-r \quad 3.14$$

Condition 1 has already been referred to and so there is no need to dwell on the circumstances under which it will be positive. The second condition just states that the rate at which goodwill depreciates should not be "too high" relative to the discount rate.

3.3.2.6 Over Time

Over time the Nerlove - Arrow result implies that with a constant goodwill elasticity and price elasticity of demand, the advertising sales ratio will fall *ceteris paribus* provided that $\delta < 1$. Since δ is the rate of decay of the stock of goodwill, this condition will always hold. When $\delta = 1$ there is no lasting effect from current period advertising expenditures and so the Dorfman-Steiner condition is applicable. In these circumstances and under the assumption of constant elasticities, then the advertising sales ratio will always be constant.

In the epidemic framework, the trend in the advertising sales ratio is more complex. Recall that in the model without goodwill effects

$$AS_1 = \frac{P-C_1}{P} \eta_{q,1} + \frac{P-C_2}{P(1+r)} \eta_{q,1} \left(\frac{\partial X_2}{\partial X_1} - 1 \right) \quad 3.7$$

$$AS_2 = \frac{P-C_2}{P} \eta_{q,2}$$

3.9

where

$$AS_1 = A_1 / PX_1$$

$$AS_2 = A_2 / P(X_2 - X_1)$$

So if the price cost margins are constant over the two periods then,

$$AS_1/AS_2 = \frac{\eta_{q1A1}}{\eta_{q2A2}} \left[1 + \left(\frac{\partial X_2}{\partial X_1} - 1 \right) \frac{1}{1+r} \right] \quad 3.15$$

Assuming that the advertising elasticities are constant over time, then whether or not

$$AS_1/AS_2 \geq 1 \quad 3.16$$

depends upon whether

$$\left(\frac{\partial X_2}{\partial X_1} - 1 \right) \geq 0 \quad 3.17$$

Provided that the dynamic owner externality is positive then the advertising sales ratios will fall over time. The greater intensity of advertising in the first period, given constant price cost margins and constant consumer sensitivity to advertising, is due to the existence of the dynamic externality attached to first period advertising.⁷

⁷ If a stock of goodwill is assumed, since $\partial q_1 / \partial A_1 = \partial q_1 / \partial G_1$ then under the same conditions, $AS_1 > AS_2$ provided that $(\partial X_2 / \partial X_1 - 1) > 2(\delta - 1)$. If $\delta = 1$, there are no goodwill effects and this condition reduces to 3.17. However, if $\delta < 1$, provided that the rate of decay is not too large, the dynamic externality can be negative so that the negative early extraction effect dominates, and yet the advertising sales ratio will still fall over time because the lasting goodwill effects of advertising compensate for the other dynamic and negative effect.

When price cost margins are constant but the advertising elasticity is declining over time such that $\eta_{q2A2} < \eta_{q1A1}$, then for $AS_1 > AS_2$ requires

$$\left(\frac{\partial X_2}{\partial X_1} - 1 \right) \frac{1}{1+r} > \frac{\eta_{q2A2}}{\eta_{q1A1}} - 1$$

3.18

If $\eta_{q2A2} / \eta_{q1A1}$ is less than 1, then the RHS of equation 3.18 will always be negative, then the advertising sales ratio will fall over time providing that the dynamic externality is positive. Without the dynamic externality, the advertising sales ratio would fall over time under the assumption of a diminishing advertising elasticity. When a positive dynamic externality is added to the model, this will serve to enhance the attractiveness of advertising in the early period and the advertising intensity will therefore be greater in the early period.

If $\eta_{q2A2} > \eta_{q1A1}$, then from 3.18 for AS_1 to be greater than AS_2 it is necessary that not only is the dynamic owner externality positive but its discounted magnitude must be such that it offsets the relative advantage of period 2 advertising resulting from the increased sensitivity of consumers to advertising expenditures over time.

Changes in the responsiveness of consumers to advertising over time will depend upon many factors (see for example Cowling *et al* 1975) which may include the amount of advertising already undertaken. If the advertising response curve is eventually subject to diminishing returns, then *ceteris paribus*, a larger potential population is likely to delay the point at which such diminishing returns set in. Over time, in this model, the remaining potential market is getting smaller, thus it is quite reasonable to assume that the advertising elasticity is decreasing over time.

In addition the type of commodity may affect consumers sensitivity to advertising, this generally being greater for luxuries, for new products, and for complex products whose characteristics cannot be substantiated before use. Also, if price is seen

as a proxy for the search benefits of consumers, then products with lower prices (and by implication low search benefits for this product) may have a greater advertising elasticity, since consumers may be reluctant to conduct extensive and therefore costly search to confirm the advertising claims. The sensitivity of consumers to advertising will also depend upon the reactions of competitors and the cyclical phase of an economy. This last point rests upon the Galbraithian notion that in boom periods more income is available for consumption of luxury goods once the necessities of life have been purchased.

Over time, given that some volume of advertising has already occurred and the remaining potential market is falling, consumers become more familiar with the new product, and may become less sensitive to advertising expenditure. On the other hand, producers may be adding to the complexity of the product by including new features and if in addition prices are falling, then the responsiveness of consumers to advertising may actually increase over time⁸. Consequently it is not easy to say *a priori* whether a constant, increasing or decreasing advertising elasticity is more applicable. Provided that a constant or declining advertising elasticity is assumed (with constant price cost margins), then a falling advertising sales ratio will be the outcome, subject only to the requirement that the dynamic owner externality is positive. The conditions under which this holds have already been discussed above.

3.3.2.7 Summary

To summarise, in an epidemic demand diffusion framework with a monopolist supplier, the profit maximising advertising sales ratio in period 1 will be larger or smaller than that given by the standard Dorfman-Steiner condition depending upon whether the dynamic owner externality is positive or negative respectively. This condition may be stated as,

$$\beta \left[1 - \frac{2X_1}{N} \right] - \alpha_2 \gtrless 0 \quad 3.19$$

⁸ Falling real prices of new consumer durables is often observed in practice.

In comparison to the standard Nerlove Arrow condition, the first period goodwill sales ratio in the epidemic model will be larger, provided that the dynamic owner externality is positive (equation 3.5) and that

$$2\delta > 1-r \quad 3.14$$

Over time, with constant advertising and price demand elasticities, the Dorfman Steiner condition suggests constant advertising sales ratios, whereas under these same assumptions the Nerlove Arrow expression will show declining advertising intensity.

In the epidemic framework what happens to the advertising sales ratio over time is more complex. Assuming that price cost margins and advertising demand elasticities are constant then the profit maximising advertising sales ratios will fall over time provided that the dynamic owner externality is positive (but when the goodwill effect of advertising is also included, the advertising sales ratio will still decline even when the negative early extraction effect dominates provided that the rate of depreciation of the goodwill is not too large).

If the price cost margin is constant but advertising demand elasticity declines over time then (if the dynamic owner externality is positive), advertising intensity will fall over time.

If the price cost margin is constant but advertising demand elasticity is increasing over time then the advertising sales ratio will fall over time only if the dynamic owner externality is positive and its magnitude is such that it offsets the disadvantage of the lower contemporaneous advertising responsiveness in earlier periods

3.3.3 The Theoretical Model; More than One Supplier

The supply side factors can be just as important in determining the shape of the diffusion path as the demand factors concentrated upon so far. This will become clearer once the epidemic framework above is extended to accommodate a supply sector with more than one firm. Multiple suppliers introduce rivalrous behaviour and this will impinge upon the firm's advertising expenditure decision. The key factor isolated in the

epidemic model under monopoly conditions is the existence of a dynamic externality, all of the benefit will accrue to the monopolist supplier.⁹ Allowing for at least one more producer in this framework adds to the decision problem because each producer must recognise mutual interdependence. Intuitively it is obvious that although the dynamic externality will still exist, the potential for one firm to secure all of the dynamic benefit resulting from its own behaviour will be limited. To see this more clearly, there are some issues and additional assumptions which need to be considered.

3.3.3.1 Intra Product Heterogeneity

Relaxing the monopoly supplier assumption means that further complications are introduced. Once the assumption of a single producer of the new product is abandoned, heterogeneity of the product should be recognised so that more than one price can hold in the market at any one time. Product differentiation between the new and existing good has been mentioned. However in moving from monopoly to oligopoly in the supply of the new product an implicit assumption of intra product homogeneity will be made. This provides a logical contradiction once a firm's advertising is allowed to affect brand share.

Whereas this may appear open to criticism, the primary focus of the analysis here is the role of advertising in the diffusion of the generic product rather than on a particular brand. Whilst the inclusion of the latter may add richness to the specification, it would also cloud the issue under investigation, namely whether advertising has a role in spreading the ownership of a new generic product amongst the population and is unlikely to yield further insights into this particular question. There are basically two approaches that have been adopted in the literature to overcome this problem of product heterogeneity. Price can be assumed to be exogenously determined and the analysis concentrates upon advertising as the decision variable and to quote Schmalensee (1972),

⁹ It will be a benefit provided that the information carrier effect offsets the negative early extraction effect as discussed earlier.

Such models..... are incomplete since they do not consider firms' price (or output) decisions. Logically, though, they are no less complete than price-output models in which selling expenditures are exogenous.

Alternatively product heterogeneity can implicitly be recognised but a symmetry rule be invoked, such that only one price exists in industry equilibrium (Cubbin 1974).

In effect, both of these approaches will be used because each one is more appropriate to one of the two particular diffusion models given their underlying features. The approach adopted by Schmalensee with price exogenously determined will be used for the epidemic model presented in this chapter because the population is assumed to be homogeneous. In the probit type diffusion model the population differs with respect to some characteristic and hence price can be used as a decision variable, so the symmetry rule will be invoked.

3.3.3.2 Heterogeneous Advertising and Market Share

It is assumed that,

- i) total industry advertising, the summation of individual firms' advertising expenditures, will determine total industry stock demand.
- ii) each firm's market share will depend upon their share of total advertising spend and such expenditure will be equally effective, so that quality differences of advertising campaigns are ignored.

In reality the second assumption may appear naive. However allowing for heterogeneous advertising expenditures becomes highly subjective. Lambin (1970) did attempt to incorporate this factor by using dummy variables to represent advertising of two particular brands of petrol as 'image-building' and other 'promotional' campaigns, but

this approach can still be criticised for being subjective, as the researcher has to allocate expenditure to each of these categories.

However Chiplin and Sturgess (1981) consider that the problem is not so important to the final econometric results if, as they believe, differences in advertising quality are random across firms and over time. So they conclude 'differences in copy quality should not persistently bias results based upon aggregate data'. Given the focus of attention of the analysis and the ultimate desire to test empirically the impact of advertising on the diffusion curve, the assumption of homogeneous advertising is probably an acceptable simplifying assumption. The lack of recognition of this factor would of course be more serious if the primary interest was at the firm level, when the issue would need to be addressed.

Given the fact that intra product heterogeneity and advertising heterogeneity are being ignored, some allocation rule must be specified for the effectiveness of a firm's individual advertising expenditure. It is assumed that total industry advertising, which is the summation of advertising expenditures undertaken by all firms within the industry, affects industry demand due to its informative role. It is then assumed that this demand is distributed amongst firms in relation to the firm's share of total advertising expenditures, ie $s_{it} = a_{it} / A_t$.

Hence the greater the intensity of an individual firms advertising relative to the industry total, the more likely it is that consumers will receive information from this firm and so buy its product. Given that, by assumption, the model is not explicitly concerned with intra product heterogeneity, this would seem a reasonable allocation rule. Current advertising expenditures are thus assumed to contain information about the generic product and the different suppliers of the good.

3.3.3.3 Market Share and Loyalty Effects

In addition to the current effect of advertising expenditures, information will be carried forward into the future by the new owners. This spread of information will affect the buying behaviour of the remaining non owners in the population. Upon receiving the 'word of mouth' information, these non owners will purchase the new product, about which they were previously ignorant. It will be assumed that the information transmitted is purely of a generic nature ie about the product *per se*, rather than any particular brand. Thus the model abstracts from the possibility of goodwill or loyalty effects in market shares¹⁰. Given that the dynamic information externality is generic in nature and there are no goodwill or loyalty effects from current market share, an individual firm will have to undertake future advertising in order to secure any future benefit from the dynamic externality.

This future advertising represents an additional cost which is incurred by an oligopolist but would not be necessary if only one supplier existed. Thus the dynamic information externality is no longer free, as is the case for a monopolist. This additional payment is bound to affect the advertising decision. In addition, the precise outcome is also dependent upon a firms attitude to the mutual interdependence and its expectations of competitors reactions. The model will follow the standard Cournot assumption of zero conjectural variations but this will be relaxed and discussed informally later in the chapter.

To summarise, assuming there is more than one supplier, each holding zero conjectural variations, and that a firm's current market share is dependent upon its relative current advertising share. There are no market share loyalty effects as the dynamic information transmitted is of a generic nature. Under these conditions, current advertising by a firm will have the effect of increasing both current industry demand and its own current market share. In the next period, there will be a positive dynamic information

¹⁰ The implications of relaxing this assumption will be discussed later.

carrier effect, however due to the generic nature of the information flow this benefit will be shared amongst all producers.

In addition, there is the negative early extraction effect and this will also be borne by all firms in the industry. Provided that the net outcome of this dynamic owner externality is positive, then this benefit will be shared by all firms undertaking advertising in the future period. The requirement of an extra cost to secure this dynamic benefit will act to discourage an oligopolist firm from undertaking the same volume of first period advertising as a monopolist.

3.3.3.4 First Order Conditions

Given the conditions described above, an oligopolist i will maximise discounted profits π_i

$$\pi_i = P s_{i1} X_1 - c_{i1} s_{i1} X_1 + \frac{P}{1+r} s_{i2} (X_2 - X_1) - \frac{c_{i2}}{1+r} s_{i2} (X_2 - X_1) - a_{i1} - \frac{a_{i2}}{1+r}$$

3.20

subject to the demand diffusion equation 3.1 by the choice of advertising in each period.

X_1 = Total industry cumulated unit sales in period 1 (since by assumption owners purchase one unit only).

X_2 = Total industry cumulated unit sales in period 2.

therefore

$(X_2 - X_1)$ = Total industry quantity sold in period 2.

s_{it} = An oligopolist's market share of total industry sales in period t and s_{it} is a function of the oligopolist's advertising share ie. a_{it}/A_t .

a_{it} = Oligopolist's advertising expenditure in period t .

A_t = Total industry advertising expenditures in time t .

C_{it} = Marginal cost for an oligopolist in period t (assumed constant).

P = Long run oligopoly industry equilibrium price.

r = Discount rate.

As before, marginal costs within a period will be assumed constant but can vary across periods. Firms are assumed to adopt zero conjectural variations behaviour. The full model and derivation of the first order conditions are given in appendix 3.4 at the end of this chapter.

The first order conditions for advertising in period 1 are reproduced in equation 3.21. An oligopolist will advertise in period 1 up to the point where the marginal benefit equals the marginal cost of advertising, such that,

$$(P - C_1) \left[\frac{X_1}{A_1} (1 - s_{11}) + s_{11} \frac{\partial X_1}{\partial A_1} \right] + \left[\frac{P - C_2}{1+r} s_{12} \frac{\partial X_1}{\partial A_1} \left(\frac{\partial X_2}{\partial X_1} - 1 \right) \right] = 1 \quad 3.21$$

The marginal benefit includes the standard current industry effect $(P_i - C_{i1}) \cdot s_{i1} \cdot (\partial X_1 / \partial A_1)$ and the current market share effect $(P_i - C_{i1}) \cdot X_1 / A_1 \cdot (1 - s_{i1})$. However in this particular model, there is an additional element in the marginal benefit, ie, the firms share of the discounted dynamic externality, $(P_i - C_{i1} / (1+r)) \cdot s_{i2} \cdot (\partial X_1 / \partial A_1) \cdot (\partial X_2 / \partial X_1 - 1)$. This dynamic benefit depends upon the period 2 advertising share. Unless the individual firm undertakes some second period advertising so that $s_{i2} > 0$, it will not capture any of this dynamic benefit that has partially arisen from its previous advertising expenditure.

Compared to the monopolist, an oligopolistic firm must consider the fact that rivals in the next period can benefit from its current advertising expenditures. In other

words, the firm will be providing a free benefit to its rivals in the next period. This will have the negative effect of reducing the volume of first period advertising undertaken by an individual oligopolist. This result arises due to the generic nature assumed for the information carrier effect. The effect on the result if this generic assumption is relaxed will be discussed later.

3.3.3.5 Industry Advertising Sales Ratio

Assuming there are n symmetric firms, each facing the same cost conditions and holding the same Cournot conjectures about the behaviour of rivals, and summing across n to obtain the industry advertising sales ratio gives the following conditions,

$$A_1/PX_1 = \left[1 - \frac{1}{n}\right] \left[\frac{P-C_1}{P}\right] + \frac{1}{n} \left[\frac{P-C_1}{P}\right] \eta_{q,11} + \frac{1}{n} \left[\frac{P-C_2}{P}\right] \frac{\eta_{q,11}}{1+r} \left[\frac{\partial X_2}{\partial X_1} - 1\right] \quad 3.22$$

$$A_2/PX_2 = \left[1 - \frac{1}{n}\right] \left[\frac{P-C_2}{P}\right] + \frac{1}{n} \left[\frac{P-C_2}{P}\right] \eta_{q,21} \quad 3.23$$

Over time, given the number of firms and assuming a constant price cost margin in both periods, then $AS_1 > AS_2$ provided that

$$\left[\frac{\partial X_2}{\partial X_1} - 1\right] \frac{1}{1+r} > \frac{\eta_{q,21}}{\eta_{q,11}} - 1 \quad 3.18$$

Obviously this is the same condition derived earlier in equation 3.18 for $n = 1$ since although the within period ratios are likely to differ with respect to the number of supplying firms, the change in this ratio over time will still rest upon the intertemporal requirement that the current and discounted dynamic benefit of period 1 advertising is greater than the current period 2 effect. As the circumstances under which this condition

will hold have already been discussed for the case of a single supplier firm, there is no need to dwell further upon this particular aspect.

3.3.3.6 Market Structure and the Industry Advertising Sales Ratio

Traditionally, investigation of the determinants of advertising across markets has tended to concentrate upon the degree of seller concentration in the market. There is some debate in the literature about the sign of the relationship between the advertising intensity and the number of firms within an industry (Cable 1972). Under the assumptions of equal size firms with equal costs and advertising effectiveness adopting Cournot quantity setting behaviour, then the standard Dorfman Steiner condition gives,

$$\frac{A}{PX} = \frac{n-1+\eta_A}{n\eta_P} \quad 3.24$$

This corresponds exactly to the advertising sales ratio for period 2 in the epidemic model 3.23 above.¹¹ The sign of the derivative of this ratio with respect to n is ambiguous and will depend upon the values assumed for the advertising elasticity.¹²

What can be said about the impact on the advertising sales ratio in the epidemic model as the number of suppliers increases? In general no conclusions can be drawn about the change in the ratio with respect to the number of firms n . There are the two limiting cases,

1. when $n = 1$, the monopolist result given in equation 3.7 holds and
2. as $n \rightarrow \infty$ then the advertising sales ratio is equal to the price cost margin.

In between these two extremes, the outcome is more ambiguous. However, it is this first period which is of most interest. The approach adopted here will be to

¹¹. Except that the price cost margin has been substituted with its profit maximising condition, namely $1/n\eta_P$.

¹². See Waterson (1984) for some numerical examples.

investigate some special cases to obtain an indication of the effect of a change in n on the first period advertising sales ratio. Ignoring for the moment the additional complexity that the price cost margin will be a function of the number of supplier firms, and further assuming the advertising elasticities and the dynamic owner externality are all invariable with respect to the number of firms then,

$$\partial AS_1 / \partial n = \frac{(P - C_1)}{P} \frac{1}{n^2} (1 - \eta_{q1A1}) - \frac{(P - C_2)}{P(1+r)} \frac{\eta_{q1A1}}{n^2} \left[\frac{\partial X_2}{\partial X_1} - 1 \right] \quad 3.25$$

If the advertising elasticity η_{q1A1} is constant then the first term on the RHS of equation 3.25 will be negative, positive or zero subject to the value of η_{q1A1} . The second term on the RHS of equation 3.25 will be positive, negative or zero dependent upon the sign of the dynamic owner externality $(\partial X_2 / \partial X_1 - 1)$.

For example, if $\eta_{q1A1} > 1$ and $(\partial X_2 / \partial X_1 - 1) > 0$ the advertising intensity will be greater under monopoly than an industry having more than one supplying firm (provided that suppliers do not collude to act as a monopolist, the likelihood of which and its implications will be discussed later).

If $\eta_{q1A1} < 1$ and $(\partial X_2 / \partial X_1 - 1) > 0$, the advertising intensity will still be larger under monopoly provided that the current period industry and market share effect of A_1 does not offset the fact that the oligopolistic firm only secures a share of the dynamic benefit, ie. the relative magnitude of the second term on the RHS of equation 3.25 must outweigh the positive first term. This accords with the intuitive explanation given earlier that the existence of an extra cost incurred by an oligopolist in obtaining any of the dynamic benefit would tend to lower the amount of advertising undertaken by an individual oligopolist.

Now allow the price cost margin to vary with respect to n , but again assume the advertising elasticity and dynamic owner externality are invariable to the differing supply conditions, then,

$$\frac{\partial AS_1}{\partial n} = \frac{-2}{n^3 \eta_p} \left[n - 1 - \eta_{q,A_1} \right] + \frac{1}{n^3 \eta_p} \left[1 - \frac{\eta_{q,A_1}}{1+r} \left(\frac{\partial X_2}{\partial X_1} - 1 \right) \right] \quad 3.26$$

The sign of this expression 3.26 will depend upon various assumptions made about the parameters and in general no conclusion can be reached.

One special example provides evidence of the intuitive result expected, namely that the advertising sales ratio will be decreasing in n . This result holds when a constant unitary advertising elasticity and a relatively large present value of the dynamic owner externality are assumed.

As can be seen, the signing of condition 3.26 is very complex even with certain restrictive assumptions. Unfortunately, the position is in fact even more difficult because assuming that the owner externality is invariable with respect to n is not really plausible since it is endogenous to this particular model. From equation 3.1 the diagrams below can be drawn. Figure 1 is the epidemic equation curve 3.1 showing period 2 flow demand $(X_2 - X_1)$ as a function of period 1 stock X_1 .

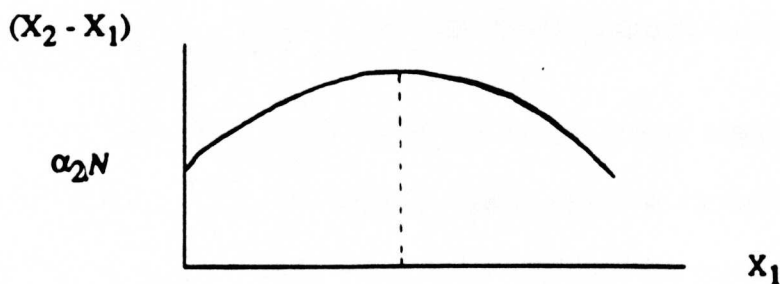


Figure 1

As can be seen in figure 1, the position of the curve will shift in response to the effectiveness of period 2 advertising. Figure 2 below, shows the dynamic owner externality equation 3.4 and is obviously the gradient of the curve in figure 1.

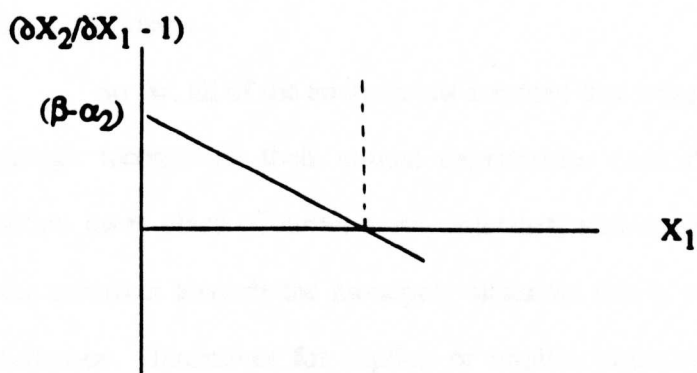


figure 2

The dynamic owner externality function (equation 3.4) will shift in response to the effectiveness of period 2 advertising. If $\alpha_2 > \beta$ then the dynamic owner externality will always be negative.

In addition, although it may be reasonable to assume a constant advertising elasticity of demand in the first period, given the functional form of the epidemic model, the second period advertising elasticity will be endogenous and therefore not constant.¹³ So although in the second period there is no dynamic externality to cause problems in the comparison, the endogeneity of the second period advertising elasticity is a major stumbling block.

3.3.4 Market structure, Industry Advertising Sales Ratio and Diffusion; An Informal Approach

These complexities make any formal general assertions on the effect on the advertising sales ratio of changing supply conditions impossible. However at a more informal level, given the assumptions already described, especially the crucial assumption that the information transmitted is of a generic nature, intuitive reasoning would suggest that an oligopolistic industry would have a lower advertising intensity in the first period relative to a monopolist. Presumably this is because of the inability of oligopolistic firms to secure all of the positive information externality, other firms being able to seize a share of this benefit by advertising in the second period.

¹³ For example this assumption will hold if $\alpha_1 = \chi A_1^S$ since $X_1 = \alpha_1 N$.

3.3.4.1 Collusion

So far, all of the analysis has assumed that where more than one supplier exists, although recognising their mutual dependence, each firm nonetheless acts as if no reaction takes place (Cournot zero conjectural variation). As the number of supplying firms contracts towards the monopoly situation, this is obviously a dubious behavioural assumption. Incentives for explicit or implicit collusion exist such that the group of colluding firms may seek the joint profit maximising outcome. Due to the nature of a two period model, there will be a difference between the first and second period outcome.

In the second period, the analysis becomes static. Thus advertising by an oligopolist in this period is primarily about market share. So it is likely that such expenditures will exceed those of the joint profit maximising situation. There is an incentive to collude, however the agreement, whether tacit or overt, can prove difficult to police. Although deviations away from the agreed levels may be easier to witness than for price collusion, retaliation is more awkward. It can take time before a rival's promotional campaign can be matched and, in reality, such campaigns are not homogeneous (as assumed in the formal model). There can be no guarantee that a rival's campaign can be nullified. So the credibility of retaliation and perceived loss inflicted is lower and if the gains from cheating outweigh the loss when the cartel breaks down, the situation will be highly unstable. In addition, the artificial assumption of no future in the second period ensures that cheating in this final period is more or less guaranteed.

In the first period, with the information transmitted limited to being generic in nature, the intertemporal joint profit maximising outcome for an oligopolistic firm probably requires an agreement to increase the level of expenditures above that which would be undertaken in the absence of collusion. Presumably, this would be extremely difficult to enforce as an individual firm would be tempted to 'free ride' and obtain the future benefit of rival's current advertising expenditure. The credibility of the 'free ride' is likely to be lower when the number of firms in the agreement is small. Say there are only two suppliers, each is likely to perceive that a reduction in their contribution to the pool

of information carriers will mean that the future total benefit will be negligible, if it exists at all (as the other duopolist could also reduce its contribution). Consequently the expected intertemporal loss from breaking the collusive agreement will be relatively large. When allowance is made for loyalty effects, the incentives to cheat are probably intensified because of the relatively large intertemporal gains arising from the possible simultaneous existence of loyalty effects of first period market share and the incentive to race to extract the marginal buyer (due to the negative early extraction effect which is borne by all suppliers in the next period).

To summarise, the chances of a successful collusive agreement are unlikely in this particular framework. However collusion is possible with the special assumption of generic information flows, provided that the number of supplying firms in the industry is very small.

3.3.4.2 Entry

The model has been derived under the assumption that the number of supplying firms n is given over the two periods, ie. the possibility of entry and exit has been ignored. Relaxing this is likely to have important consequences. Consider the case where in period 1 there is a monopolist supplier but entry can occur before period 2 commences. If the monopolist recognises the possibility of entry in the second period, then he can no longer expect to reap all of the dynamic benefit arising from his first period decisions. He will bear the cost of the first period advertising expenditures but under the expectation of entry, the monopolist will have to incur a further cost in terms of second period advertising to secure a share of the dynamic gain. Effectively then, under the threat of future entry, the monopolist in the first period will act as if more than one firm exists in the first period (of course the monopolist will not be concerned with the distributive effect of advertising in the current period). Thus the level of advertising will probably be lower than would be the case with closed entry.

This result is unusual since advertising expenditures are normally seen as a barrier to entry via their creation of brand loyalty. Such a loyalty barrier will be expensive for any potential newcomer to overcome and therefore place the entrant at a possible cost disadvantage to the incumbent. This would imply that a monopolist may undertake more advertising (compared to a situation of closed current and future entry) provided that the threat of entry is recognised and credible, rather than less.

3.3.4.3 An Invitation to Entry

The opposing results emerge because the epidemic framework explicitly takes account of the newness of the product and hence the lack of information about its existence. With the assumption of generic information flow between individuals, the firm who contributes to the pool of information cannot solely exploit it. Thus advertising expenditures will encourage new entrants (an 'invitation to entry') not deter them. It will have a knock-on effect, providing a greater pool of information, thus a greater number of potential buyers in the next period, ready for the new entrant to exploit.

3.3.4.4 Loyalty Effects of Information Flows

Of course, if the assumption of generic information flow is abandoned, it is likely that this result will change. Allowing for loyalty effects such that a firm's second period market share s_{i2} depends not only on current advertising share but also on previous advertising share, would then mean that it would no longer be necessary for a firm to undertake second period promotion to secure part of the positive information externality created by previous advertising. In these circumstances, the largest advertiser in the earlier period not only obtains the advantage then, but the benefit of past actions carry forward.

So for an oligopolist facing entry, allowing for loyalty effects tends to mitigate the incentive to lower advertising (which follows from the problems of securing the spill-

over information benefit in the future). However the intertemporal behaviour of the oligopolistic firm will not simply reflect that of a monopolist (who with closed entry, always obtains the future benefit of current actions). This is because of another peculiarity of the model, namely the lack of a repeat demand. Given that individuals buy one unit only, a firm has also to take account of the negative early extraction penalty (recall that the dynamic owner externality is comprised of two opposing forces, the positive information carrier effect and the negative early extraction effect).

With only one firm in both periods, the consequences of early extraction are suffered solely by the agent whose actions led to the situation. However when $n > 1$, the individual firm is no longer uniquely accountable for its actions. In effect the early extraction penalty is shared by all firms in the market. Each firm will not wish to bear this cost without receiving any of the earlier benefit and so it is likely that firms will race to extract the consumers. Coupled with the loyalty effect (which offsets the tendency for an oligopolist to reduce advertising expenditures in the generic information case), this will serve to increase the advertising of an oligopolist industry relative to a monopolist.¹⁴

To summarise, under conditions of monopoly in period 1 with the threat of entry and generic information flow, the monopolist is likely to advertise less than would have been the case with closed entry. The conclusion that a monopolist's advertising expenditures will attract entry is unusual and a result of the special feature of this particular model.

For an oligopoly situation with the threat of entry and generic information flow, there are two effects which work in opposite directions. There will be an incentive to reduce advertising because of the problem of securing the dynamic information benefit but there may be an incentive to increase advertising because the new firms in the next

¹⁴ Without the loyalty effect, this increase in advertising expenditures due to the race to extract, may offset the lower expenditures expected as a result of the problem of securing the benefit from the information flow. If the overall dynamic owner externality is positive, then the information effect dominates and consequently there will be a tendency towards lower advertising.

period will be forced to share the burden of early extraction encouraging a race to extract the marginal buyer. The net effect is ambiguous.

For an oligopolist firm and entry, but allowing for loyalty effects in the dynamic information flow, it is likely that advertising will increase compared to the same situation without entry, because the race to extract will be enhanced by the ability of firms to gain some of the dynamic information externality as a result of previous advertising.

3.4 CONCLUSIONS

The explicit recognition of the diffusion of new consumer durables has substantial consequences for the profit maximising advertising sales ratio. Existing theoretical work in the literature has included advertising in an epidemic framework. However relatively little attention was given to the associated supply side and resulting implications for the advertising decision. The time path of advertising (without any additional goodwill effects) for a monopolist supplier in an epidemic model has been investigated. The work in this chapter explored the profit maximising advertising and goodwill sales ratios within an epidemic framework both for a monopolist and oligopolistic industry.

It was found that the special features of explicitly recognising new consumer durables within a dynamic framework impinged upon these ratios. Compared to the D-S condition (which was derived from a static framework and did not account for new consumer durables *per se*) the first period advertising sales ratio in the epidemic model was found to be larger or smaller than the D-S condition, dependent upon the sign of the dynamic owner externality. This term was a special feature of the epidemic model and its sign ultimately came down to the relative magnitude of the effectiveness of the social contact information flow β and the inter temporal effectiveness of the external channel of information flow α_1 and α_2 . The N-A condition does incorporate a dynamic aspect, however it was shown that the reasons for this (ie stock of goodwill) could also be justified in the epidemic model, so adding a further dynamic feature into the profit

maximising advertising and goodwill sales ratios derived from the epidemic framework. Again, whether the advertising sales ratio with a goodwill effect in the epidemic model, was larger or smaller than the N-A condition rested on the sign of the dynamic owner externality and the additional condition that the goodwill depreciation rate was not 'too high' relative to the time discount rate.

Next, the time path of the advertising sales ratio in the epidemic framework was considered. Various cases were explored. Taking the simple case where the price cost margins and advertising demand elasticities are constant over time, the D-S condition would suggest a constant ratio. Under the same assumptions, the N-A condition would indicate a falling one. In the epidemic model, without goodwill effects, the advertising sales ratio would decrease, increase or remain constant dependent upon the sign of the dynamic owner externality being positive, negative or zero respectively. When goodwill effects are also included then under these same assumptions, the advertising sales ratio in the epidemic model could still fall over time even if the dynamic owner externality was negative (which would be the case if the negative early extraction effect dominates), provided that the lasting effects of advertising due to the stock of goodwill compensated for this negative early extraction effect. If this was not the case, the advertising sales ratio would increase over time and not decrease as suggested by the N-A condition. This is obviously a result of noting the further dynamic aspects of investigating new consumer durables.

In the existing literature, the effect of concentration on the advertising sales ratio in a static framework has been considered. The resulting advertising sales ratio in an oligopolistic industry was found to be higher or lower than for a monopolist dependent upon the number of firms in the industry and value of the advertising elasticity. The work in this chapter also looked at the effect of a changing number of suppliers on the profit maximising sales ratios when derived within a dynamic epidemic framework. The ambiguity of the effect of concentration on the advertising sales ratio was intensified. However at an intuitive level, the oligopolistic industry advertising sales ratio was

expected to be lower than for a monopolist because of the inability of oligopoly firms to secure all of the dynamic externality in the future period. An advertising sales ratio decreasing in the number of firms in the industry was confirmed in the formal model under the special assumptions of a constant unitary advertising elasticity and a relatively large discounted value of the dynamic owner externality (although this had to be treated with caution given that the dynamic owner externality was itself endogenous).

Finally, an informal approach was adopted and the effect of relaxing some of the market structure assumptions explored. The Cournot conjectural variation assumption was relaxed and the likelihood of collusion discussed. On the whole, this was considered unlikely in this particular epidemic framework except under the special assumptions of generic information flows and a small number of suppliers in the industry.

When the threat of entry was recognised, unlike the standard case in the literature (Bain 1968), advertising was not seen as a barrier but an invitation to entry. This occurred under the special assumption of a generic information flow. Consequently, the profit maximising advertising sales ratio would be lower than for a monopolist secure from potential entry. In an oligopolistic industry, the effect was ambiguous due to the opposing forces of the positive information and negative early extraction effects. However, relaxing the generic information assumption and allowing for loyalty effects in the information flow, the threat of entry would tend to increase the advertising intensity. This was likely because the race to extract prompted by the negative early extraction effect would be enhanced by loyalty effects in the information externality.

APPENDIX 3.1

(For a full description of the variables, refer to page 60 in chapter 3.)

A monopolist will maximise the following profit function (in stock terms):-

$$\pi = PX_1 + \frac{P}{1+r}X_2 - \frac{P}{1+r}X_1 - C_1X_1 - \frac{C_2}{1+r}X_2 + \frac{C_2}{1+r}X_1 - A_1 - \frac{A_2}{1+r}$$

Subject to the following stock demand functions (based upon an epidemic demand diffusion model)

$$X_1 = \alpha_1 N$$

$$\alpha_1 = f(A_1)$$

Since there are no previous owners $X_0 = 0$, stock demand in period 1 X_1 will depend upon the size of the given population N and total advertising in period 1 α_1

$$X_2 = \left[\beta \frac{X_1}{N} + \alpha_2 \right] (N - X_1) + X_1$$

The total stock demand in period 2 X_2 is based upon the epidemic diffusion model. In addition to information flows by advertising, in period 2 there will be existing owners to pass on information by word of mouth.

The first order condition with respect to the advertising variable in period 1 is,

$$\frac{\partial \pi}{\partial A_1} : \left[P - \frac{P}{1+r} - C_1 + \frac{C_2}{1+r} \right] \frac{\partial X_1}{\partial A_1} + \left[\frac{P - C_2}{1+r} \right] \frac{\partial X_2}{\partial A_1} = 1$$

where $\frac{\partial X_2}{\partial A_1} = \frac{\partial X_2}{\partial X_1} \frac{\partial X_1}{\partial A_1}$ as can be clearly seen from the stock demand function in period 2 above.

substitute for $\frac{\partial X_2}{\partial A_1}$ and multiply through by $\frac{A_1}{PX_1}$

Gives the profit maximising advertising sales ratio in period 1,

$$\frac{A_1}{PX_1} = \frac{(P - C_1)}{P} \epsilon_{X_1 A_1} + \frac{(P - C_2)}{P(1+r)} \epsilon_{X_1 A_1} \left[\frac{\partial X_2}{\partial X_1} - 1 \right]$$

1

where

$$\epsilon_{X_1 A_1} = \frac{\partial X_1}{\partial A_1} \frac{A_1}{X_1}$$

The first order condition with respect to the advertising variable in period 2 is,

$$\frac{\partial \pi}{\partial A_2} : \frac{P}{1+r} \frac{\partial X_2}{\partial A_2} - \frac{C_2}{1+r} \frac{\partial X_2}{\partial A_2} = \frac{1}{1+r}$$

$$\left(\frac{P-C_2}{1+r} \right) \frac{\partial X_2}{\partial A_2} = \frac{1}{1+r}$$

multiply through by $\frac{A_2}{PX_2}$

Gives the profit maximising advertising stock ratio in period 2,

$$\frac{A_2}{PX_2} = \left(\frac{P-C_2}{P} \right) \epsilon_{X_2 A_2} \quad 2$$

where

$$\epsilon_{X_2 A_2} = \frac{\partial X_2}{\partial A_2} \frac{A_2}{X_2}$$

The elasticity of stock demand in period 2 to second period advertising.

Note that the denominator in equ 2 is the total cumulated undiscounted revenue over the two periods. Thus we need to amend this ratio to show advertising flows as a ratio of period 2 revenue only.

Gives the profit maximising advertising sales ratio in period 2,

$$\frac{A_2}{P(X_2-X_1)} = \left(\frac{P-C_2}{P} \right) \epsilon_{X_2 A_2} \frac{X_2}{(X_2-X_1)} \quad 3$$

APPENDIX 3.1B

A monopolist will maximise the following profit function (in flow terms):-

$$\pi = PX_1 + \frac{P}{1+r}(X_2 - X_1) - C_1X_1 - \frac{C_2}{1+r}(X_2 - X_1) - A_1 - \frac{A_2}{1+r}$$

Subject to the following flow demand functions (based upon an epidemic demand diffusion model)

$$X_1 = \alpha_1 N$$

$$(X_2 - X_1) = \left[\beta \frac{X_1}{N} + \alpha_2 \right] (N - X_1)$$

where $\alpha_i = f(A_i)$

The first order condition with respect to the advertising variable in period 1 is,

$$\frac{\partial \pi}{\partial A_1} : P \frac{\partial X_1}{\partial A_1} + \frac{P}{1+r} \frac{\partial (X_2 - X_1)}{\partial A_1} - C_1 \frac{\partial X_1}{\partial A_1} - \frac{C_2}{1+r} \frac{\partial (X_2 - X_1)}{\partial A_1} = 1$$

where $\frac{\partial (X_2 - X_1)}{\partial A_1} = \left[\frac{\partial X_2}{\partial X_1} - 1 \right] \frac{\partial X_1}{\partial A_1}$

substitute for $\frac{\partial (X_2 - X_1)}{\partial A_1}$ and multiply through by $\frac{A_1}{PX_1}$

Gives the profit maximising advertising sales ratio in period 1,

$$\frac{A_1}{PX_1} = \frac{(P - C_1)}{P} \eta_{q11} + \frac{(P - C_2)}{P(1+r)} \eta_{q11} \left[\frac{\partial X_2}{\partial X_1} - 1 \right]$$

where

The elasticity of flow demand in period 1
to first period advertising.

$$\eta_{q11} = \frac{\partial X_1}{\partial \alpha_1} \frac{\partial \alpha_1}{\partial A_1} \frac{A_1}{X_1}$$

$$\frac{\partial \pi}{\partial A_2} : \frac{P}{1+r} \frac{\partial (X_2 - X_1)}{\partial A_2} - \frac{C_2}{1+r} \frac{\partial (X_2 - X_1)}{\partial A_2} = \frac{1}{1+r}$$

$$\left[\frac{P - C_2}{1+r} \right] \frac{\partial (X_2 - X_1)}{\partial A_2} = \frac{1}{1+r}$$

multiply through by $\frac{A_2}{P(X_2 - X_1)}$ and multiply by $(1+r)$

Gives the profit maximising goodwill sales ratio in period 2,

$$\frac{A_2}{P(X_2 - X_1)} = \frac{(P - C_2)}{P} \eta_{q22}$$

where

The elasticity of flow demand
in period 2 to second period
advertising.

$$\eta_{q22} = \frac{\partial (X_2 - X_1)}{\partial \alpha_2} \frac{\partial \alpha_2}{\partial A_2} \frac{A_2}{(X_2 - X_1)}$$

APPENDIX 3.2

Nerlove - Arrow two period model derivation.

(For a full description of the variables, refer to page 68 in chapter 3).

$$\pi = P_1 q_1 + \frac{P_2}{1+r} q_2 - C(q_1) - \frac{C}{1+r}(q_2) - A_1 - \frac{A_2}{1+r}$$

$$q_1 = f(P_1, G_1) \quad , \quad q_2 = f(P_2, G_2)$$

$$G_1 = A_1 \quad , \quad G_2 = A_2 + (1-\delta)A_1$$

$$\text{let } \frac{\partial C}{\partial q_1} = C_1 \text{ and } \frac{\partial C}{\partial q_2} = C_2$$

$$\frac{\partial \pi}{\partial P_1} = P_1 \frac{\partial q_1}{\partial P_1} + q_1 - \frac{\partial q_1}{\partial P_1} \frac{\partial C}{\partial q_1} = 0$$

$$\frac{(P_1 - C_1)}{P_1} = -\frac{1}{\eta_{q_1 P_1}} \quad (1)$$

$$\frac{\partial \pi}{\partial P_2} = \frac{P_2}{1+r} \frac{\partial q_2}{\partial P_2} + \frac{q_2}{1+r} - \frac{\partial q_2}{\partial P_2} \frac{\partial C}{\partial q_2} \frac{1}{1+r} = 0$$

$$\frac{(P_2 - C_2)}{P_2} = -\frac{1}{\eta_{q_2 P_2}} \quad (2)$$

where

$$\eta_{q_1 P_1} = \frac{\partial q_1}{\partial P_1} \frac{P_1}{q_1} \quad \eta_{q_2 P_2} = \frac{\partial q_2}{\partial P_2} \frac{P_2}{q_2}$$

$$\frac{\partial \pi}{\partial G_1} = P_1 \frac{\partial q_1}{\partial G_1} + \frac{P_2}{1+r} \frac{\partial q_2}{\partial G_2} \frac{\partial G_2}{\partial G_1} - \frac{\partial C}{\partial q_1} \frac{\partial q_1}{\partial G_1} - \frac{\partial C}{\partial q_2} \frac{\partial q_2}{\partial G_2} \frac{\partial G_2}{\partial G_1} \frac{1}{1+r} - 1 + \frac{1}{1+r} - \frac{\delta}{1+r} = 0$$

$$(P_1 - C_1) \frac{\partial q_1}{\partial G_1} + (P_2 - C_2) \frac{\partial q_2(1-\delta)}{\partial G_2(1+r)} + \frac{(1-\delta)}{1+r} = 1$$

multiply through by $\frac{G_1}{P_1 q_1}$

$$\frac{(P_1 - C_1)}{P_1} \eta_{q_1 G_1} + \frac{P_2}{P_1} \frac{(P_2 - C_2)}{P_2} \frac{\partial q_2}{\partial G_2} \frac{G_1(1-\delta)}{q_1(1+r)} = \frac{(r+\delta)}{(1+r)} \frac{G_1}{q_1}$$

substitute for price cost margins from equ 1 and 2

$$\frac{G_1}{P_1 q_1} = -\frac{\eta_{q_1 G_1}(1+r)}{\eta_{q_1 P_1}(r+\delta)} - \frac{P_2}{P_1} \frac{\eta_{q_2 G_2}}{\eta_{q_2 P_2}} \frac{G_1}{q_1} \frac{(1-\delta)q_2}{(r+\delta)G_2} \quad (3)$$

where

$$\eta_{q_1 G_1} = \frac{\partial q_1}{\partial G_1} \frac{G_1}{q_1} \quad , \quad \eta_{q_2 G_2} = \frac{\partial q_2}{\partial G_2} \frac{G_2}{q_2}$$

$$\frac{\partial \pi}{\partial G_2} : \frac{P_2}{1+r} \frac{\partial q_2}{\partial G_2} - \frac{C_2}{1+r} \frac{\partial q_2}{\partial G_2} = \frac{1}{1+r}$$

$$\frac{G_2}{P_2 q_2} = \frac{(P_2 - C_2)}{P_2} \eta_{q_2 G_2}$$

substitute for the price cost margin in equ 2

$$\frac{G_2}{P_2 q_2} = -\frac{\eta_{q_2 G_2}}{\eta_{q_2 P_2}} \quad (4)$$

substitute for equ 4 into equ 3 and rearrange

$$\frac{G_1}{P_1 Q_1} \left(1 - \frac{\eta_{G, 2P_2} \eta_{G, 2P_2} (1-\delta)}{\eta_{G, 2P_2} \eta_{G, 2P_2} (r+\delta)} \right) = - \frac{\eta_{G, 1G_1} (1+r)}{\eta_{G, 1P_1} (r+\delta)}$$

$$\frac{G_1}{P_1 Q_1} = - \frac{\eta_{G, 1G_1}}{\eta_{G, 1P_1}} \left(\frac{1+r}{r+\delta-1} \right)$$

APPENDIX 3.3

$$\pi = PX_1 + \frac{P}{1+r}(X_2 - X_1) - C_1X_1 - \frac{C_2}{1+r}(X_2 - X_1) - G_1 - \frac{G_2}{1+r} + \frac{(1-\delta)}{1+r}G_1$$

$$X_1 = \alpha_1 N$$

$$(X_2 - X_1) = \left[\beta \frac{X_1}{N} + \alpha_2 \right] (N - X_1)$$

where $\alpha_i = f(G_i)$ and N is exogenous.

$$\text{and } G_1 = A_1 \quad , \quad G_2 = A_2 + (1-\delta)A_1$$

The first order condition with respect to the stock of goodwill in period 1 is,

$$\frac{\partial \pi}{\partial G_1} = P \frac{\partial X_1}{\partial G_1} + \frac{P}{1+r} \frac{\partial (X_2 - X_1)}{\partial G_1} - C_1 \frac{\partial X_1}{\partial G_1} - \frac{C_2}{1+r} \frac{\partial (X_2 - X_1)}{\partial G_1} = \frac{r+\delta}{1+r}$$

where

$$\frac{\partial (X_2 - X_1)}{\partial G_1} = \frac{\partial X_1}{\partial G_1} \left[\frac{\partial X_2}{\partial X_1} - 1 \right] + \frac{\partial (X_2 - X_1)}{\partial G_2} \frac{\partial G_2}{\partial G_1}$$

substitute for $\frac{\partial (X_2 - X_1)}{\partial G_1}$

$$\frac{r+\delta}{1+r} = (P - C_1) \frac{\partial X_1}{\partial G_1} + \frac{P - C_2}{1+r} \left[\frac{\partial X_1}{\partial G_1} \left(\frac{\partial X_2}{\partial X_1} - 1 \right) + \frac{\partial (X_2 - X_1)}{\partial G_2} \frac{\partial G_2}{\partial G_1} \right]$$

multiply through by $\frac{G_1}{PX_1}$

$$\frac{r+\delta}{1+r} \frac{G_1}{PX_1} =$$

$$\frac{(P-C_1)}{P} \eta_{q1G1} + \frac{(P-C_2)}{P(1+r)} \left[\frac{\partial X_2}{\partial X_1} - 1 \right] \eta_{q1G1} + \frac{(P-C_2)}{P(1+r)} \eta_{q2G2} \frac{G_1}{G_2} \frac{(X_2-X_1)}{X_1} (1-\delta)$$

where

$$\eta_{q1G1} = \frac{\partial X_1}{\partial \alpha_1} \frac{\partial \alpha_1}{\partial G_1} \frac{G_1}{X_1} \quad . \quad \eta_{q2G2} = \frac{\partial (X_2-X_1)}{\partial \alpha_2} \frac{\partial \alpha_2}{\partial G_2} \frac{G_2}{(X_2-X_1)}$$

Gives the profit maximising goodwill sales ratio in period 1,

$$\frac{G_1}{PX_1} =$$

$$\frac{(P-C_1)}{P} \eta_{q1G1} \frac{1+r}{r+\delta} + \frac{P-C_2}{P(r+\delta)} \left[\frac{\partial X_2}{\partial X_1} - 1 \right] \eta_{q1G1} + \frac{P-C_2}{P} \eta_{q2G2} \frac{(X_2-X_1)}{X_1} \frac{(1-\delta)}{(r+\delta)} \frac{G_1}{G_2} \quad (1)$$

$$\frac{\partial \pi}{\partial G_2} = \frac{P}{1+r} \frac{\partial (X_2-X_1)}{\partial G_2} - \frac{C_2}{1+r} \frac{\partial (X_2-X_1)}{\partial G_2} = \frac{1}{1+r}$$

$$\left[\frac{P-C_2}{1+r} \right] \frac{\partial (X_2-X_1)}{\partial G_2} = \frac{1}{1+r}$$

multiply through by $\frac{G_2}{P(X_2-X_1)}$ and multiply by $(1+r)$

Gives the profit maximising goodwill sales ratio in period 2,

$$\frac{G_2}{P(X_2-X_1)} = \frac{(P-C_2)}{P} \eta_{q2G2} \quad (2)$$

substitute for equ 2 into equ 1 and rearrange

$$\frac{G_1}{PX_1} = \frac{(P-C_1)}{P} \frac{(1+r)}{(r+2\delta-1)} \eta_{q1G1} + \frac{P-C_2}{P} \left[\frac{\partial X_2}{\partial X_1} - 1 \right] \frac{\eta_{q1G1}}{(r+2\delta-1)} \quad (3)$$

CHAPTER 4

THE ROLE OF ADVERTISING IN A PROBIT BASED MODEL

4.1 INTRODUCTION

In this particular chapter, the alternative demand diffusion model (the probit framework) will be explored. Unlike the epidemic model, advertising has not been included into this particular framework in the existing literature. Consequently, this shall be the first priority, also, advertising will be allowed to have an independent dynamic effect through the stock of goodwill concept discussed in the last chapter. As shown in the literature review chapter, a supply side has been added to the probit demand diffusion equation but obviously, given the neglect of advertising on the demand side, no consideration has been given to the advertising decision of suppliers and the implications of using a probit structure on the resulting profit maximising advertising sales ratios. This deficiency will be addressed in this chapter. Like before, the procedure will be to derive the advertising sales ratios in the model for both a monopolist and oligopolistic industry and compare these results to the standard D-S and N-A conditions. The time path of the ratios will then be considered, as will the effect of a changing market structure (in terms of number of suppliers) on the advertising sales ratios. Finally, the advertising sales ratios derived under the same supply side assumptions but using the competing epidemic and probit demand diffusion models will be reviewed.

4.1.2 Application of the epidemic and probit frameworks

One of the major weaknesses of the epidemic framework is its lack of a decision-theoretic base and this seriously limits the extent to which important economic variables can be included in the model. In the last chapter it was suggested that the epidemic model may have limited applicability to a particular type of product innovation ie. a vertically differentiated new product. Nonetheless, although all potential consumers in the market may agree on the superiority of a vertically differentiated product, there can still be other important factors which differentiate the population of potential buyers, eg incomes may vary. Even if this was not the case, individuals may agree on the relative

superiority of the new product but disagree over the extent of its absolute improvement. Yet the epidemic model with its assumption of a homogeneous population ignores this fact.

Further, there are some products for which the epidemic model is unsuitable. For example, some new products may be better described as horizontally differentiated as a proportion of the population (due to their underlying preferences) may never be convinced of the superiority of the new product relative to an existing substitute. A simple example may help to highlight this point. The introduction of the colour television receiver is most likely an example of a vertically differentiated product. If rational consumers are faced with the choice of a colour or monochrome set, given equal prices, it is highly unlikely that anyone will choose the existing monochrome technology. Eventually one would expect to see the complete disappearance of the monochrome set (see diagram A6.1 in chapter 6 for a clear demonstration of this inevitable obsolescence). On the other hand, a new product such as a microwave oven may never completely replace the use of conventional ovens within the population. Not all individuals will be agreed on the superiority of this new product relative to the existing one, even with equivalent prices.

In reality, many new products will be both horizontally and vertically differentiated, such that this classification is blurred. Further, some products will not fit into this classification at all as they are completely new and serve a function for which no previous product existed (eg. the video cassette recorder). The probit based model, given its explicit recognition of a heterogeneous population, will be much more general in its suitability, applicable to both horizontal and vertically differentiated new products.¹ Also this framework can cope with completely new goods as well as the 'mongrel' product innovations.

¹. As explained, even a vertically differentiated product can be accommodated in these models by allowing all individuals to agree on the relative superiority of the new product, but disagree with respect to the extent of the absolute improvement.

4.2 FRAMEWORK OF ANALYSIS: SOME GENERAL ISSUES

Before introducing the model it is worthwhile reiterating the special features of the analysis in this thesis. As explained in the last chapter, the focus of attention in this thesis is on the introduction of a new consumer durable at the industry level, ie, it is the generic product that is being investigated. Also, this analysis is concerned with the decision to adopt for the first time, multiple purchases are ruled out by assumption. Further, only the early stages of the product life cycle is considered and for a consumer durable, the question of replacement purchases can be reasonably ignored.

4.2.1 Stock Demand Curves

As a result of these special assumptions, downward sloping demand curves for individuals do not exist. Instead, the notion of reservation price is used. An individual only will enter the market once the expected benefit of ownership exceeds or equals the cost of purchase and will buy only one unit. He will not re-enter the market. However at the aggregate level, the concept of a downward sloping industry demand curve can be re-employed, for it is simply the summation of the number of individuals for whom the benefit exceeds the reservation price at each price level.

4.2.2 Potential Population

The concept of the population of potential buyers for the new product also differs in this model compared to the epidemic one. An equilibrium approach is adopted in the probit type model. Let M_t be the number of individuals in the heterogeneous population. M_t will change due to demographic factors which will most likely occur slowly over a considerable period of time. Economic variables such as prices, income and in particular to this analysis, advertising, will determine the desired equilibrium stock X_t^* . Individuals respond immediately to these economic variables. So at any point the number of owners will be X_t and since an equilibrium concept is being used, $X_t = X_t^*$. Therefore X_t^* will be the total number of owners (and hence stock owned due to the assumption of unit ownership) when diffusion is complete, given the level of the relevant economic variables.

Over time the proportion of the population who are owners X_t^* / M_t will change as these economic variables alter the desired equilibrium level X_t^* . If there is no change in the economic variables, then diffusion will cease. This may occur before complete diffusion amongst the whole population, that is before $X_t = X_t^* = M_t$. The underlying assumption in probit models is one of full information. Individuals adjust to the desired equilibrium immediately due to changes in the economic variables which determine X_t^* . In a world of product innovation, this is a rather extreme assumption. It is more likely that the adjustment is partial, not least because of incomplete information.²

4.3 THE PROBIT MODEL

The probit based models begin with the basic assumption of a population of potential buyers who differ with respect to some characteristic. To become operational, the characteristic and the determination of the critical value of the characteristic need to be defined. This is explained in the following sub-sections.

4.3.1 Definition of Characteristic

New goods will be viewed as a bundle of attributes following Lancaster (1966) and Ironmonger (1972). Given his preferences for various combinations of attributes, an individual will seek to achieve the highest level of satisfaction subject to the budget constraint. The model introduced by Lancaster (1979) to account for goods whose attributes cannot be linearly combined seems an appropriate framework for adapting and appending to the probit based diffusion model as it uses physical rather than monetary values. This will become clearer in the following paragraphs.

The figure below is based on the model presented by Lancaster (1979). Assume that differences in products can be decomposed into differences in measurable attributes of these goods. These attributes will be assumed to be identifiable and quantifiable. A subset of goods will form a separable group in which all products possess attributes in common, but none of the attributes in the subset are possessed by goods outside this

² As will be seen later, the empirical model relaxes this restriction to allow for some lagged adjustment.

group. Consequently, the utility of consumers is separable between group and non group attributes. Thus the analysis can concentrate on one group at a time.

For simplicity, assume that the group to which the new product belongs contains attributes CH1 and CH2 only. The axes in figures 1 and 2 measure the quantities of these attributes CH1 and CH2. The curve PP describes the Product Differentiation Curve. It shows all possible specifications that can be produced and the resources required to produce goods of different specification, once the different goods have been normalised to give comparable units. This is achieved by assuming that the bundle of resources available is fully used to produce a single good of a given specification. There will be some maximum amount of the good that can be produced. Since the ratio of the attributes are given by the specification of this good, the maximum amount of this good will correspond to the maximum collection of attributes in the proportion determined by the given specification.

If potential product differentiation is assumed continuous, then the maximum collections will also vary continuously, and so, the locus of all such collections will be a continuous curve. Given the resources available, the shape of the curve can be expected to slope downwards to the right showing that the amount of one particular attribute can only be increased at the expense of reducing the other. If this rate of substitution was constant, then PP would be linear. However, it is more reasonable to assume that given the available resources the rate at which one attribute can be transformed into another is diminishing. In this case, the curve PP will be concave towards the origin (like the traditional production possibility frontier).

However, in reality, not all such product differentiation specifications will be available. Assume product X only currently exists and then a new product W is introduced. Each consumer has preferences for the collection of attributes CH1 and CH2 and not the goods *per se*. These preferences are assumed to follow traditional

consumption theory such that the set of indifference curves (I) are smooth, convex towards the origin and non intersecting.³

In Figures 1 and 2, Consumer 1 prefers the attribute ratio contained in product X compared to product W, in the sense that, if one unit of X is available this consumer attains his higher indifference curve I'' , compared to I' , which would be attained if one unit of the new good W was supplied instead. Meanwhile, the reverse is true for Consumer 2. For this consumer, given his preferences for the combination of attributes contained in the new product, once this new product specification becomes available, one unit will provide greater satisfaction compared to one unit of the existing product. However at this stage, no account has been taken of the relative prices or incomes of the individuals.

Maintaining the assumption that only one normalised unit of the product is available⁴ and since the diagram is drawn with attributes measured along the axes and relative quantities of the same good are defined to be proportional to the attributes content, the ratio OW_g/OW_b gives the ratio of the quantity of the available good needed to bring the consumer to the same welfare level he could attain from one normalised unit of his most preferred good instead.⁵ This ratio will be referred to as the 'compensation ratio'. For a consumer with indifference curves such as those portrayed in Figure 1, this ratio will always be greater than 1 and the further away is the new specification W from the existing good X, the larger will be this ratio. On the other hand, for a consumer with indifference curves such as those portrayed in Figure 2, this ratio will always be less than 1 and as X tends to W, so OW_g/OW_b tends to 1.

³. A full discussion of the underlying assumptions can be found in any intermediate microeconomic text, for example, Gravelle and Rees (1981).

⁴. Although if v units of resource are available, the Production Differentiation Curve (PDC) can be derived in exactly the same way with the additional assumption that the v unit PDC is a pure homothetic expansion of the one unit PDC.

⁵. Although a point such as W_g is not knowable, in principle, the compensation ratio could be determined by observation. The consumer can be asked to state what quantity of the available good is equivalent to a specified quantity of his most preferred good.

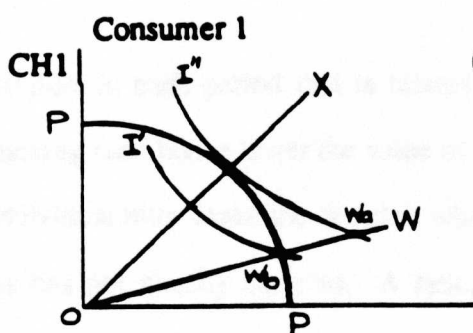


Figure 1

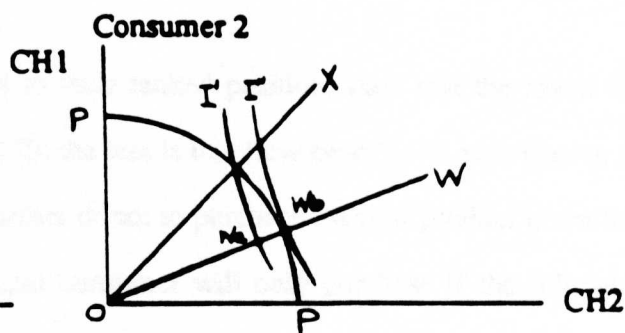


Figure 2

At this stage no account has been taken of relative prices or the individual's income. However consumers can rank the relative attractiveness of the available good to the new product introduced. It is clear that whether the individual ultimately purchases the new product will depend also upon the budget constraint. For the moment, all that is required is the definition of the distribution of potential buyers who vary with respect to some characteristic. So, assume that individuals in the population can be ranked according to the inverse of this compensation ratio (ie. $Z = 1 / (OW_g / OW_b)$), such that, the lower an individual in the ranking, the larger will be the compensation ratio and hence the lower will be the value of Z . Thus this individual is less likely to prefer the new product introduced.⁶ Let this characteristic Z be distributed $f(Z)$ with a cumulative distribution $F(Z)$. For simplicity, the variance of this distribution will be assumed constant so that relative positions in the population do not alter. However the whole distribution may shift as the mean of the distribution changes and this will be one way in which diffusion can occur. This will be discussed in more detail later, for now, assume that $f(Z)$ is invariant with respect to time.

4.3.2 Critical Level Determination

At time t , an individual is assumed to be an owner of the new product if his characteristic level Z is above some critical value Z^* . Following Stoneman and Ireland (1985), assume that individuals receive a flow of benefit $h(Z)$, from ownership of the new

⁶ For individuals with $Z > 1$, the new product is preferred relative to the old one. However the extent of the superiority will vary and will be greatest for those individual with a Z ratio closest to infinity.

product in each period that is related to their ranked position, such that the lower the ranking (and hence lower the value of Z), the less is this flow benefit. In each period, an individual must make the decision whether or not to purchase the new product given that he has not already done so. A rational consumer will only purchase if the following conditions are met,

1) Profitability condition

$$\frac{h(Z)}{r} \geq P_t \quad 4.1$$

2) Arbitrage condition

$$-P_{t+1}^e + (1+r)P_t \leq h(Z) \quad 4.2$$

where

$h(Z)/r$ = the present value of the expected flow of benefits given acquisition in time t , assuming that $h(Z)$ is constant between periods and is received in perpetuity.

P_t = the cost of acquisition in time t .

r = the discount rate.

P_{t+1}^e = the expected cost of acquisition in time $t+1$.

In order to simplify the analysis, individuals will be assumed to have myopic price expectations such that $P_{t+1}^e = P_t$. In these circumstances condition 2 becomes equivalent to condition 1. (Other possibilities with respect to price expectations are discussed by Stoneman and Ireland 1985).

As a slight digression, it is interesting to consider whether the cost of acquisition P_t is the appropriate variable to use when investigating a durable good. This good by definition will last for some considerable time, consequently by owning the asset, the purchaser acquires a title to the future stream of benefits that this asset will provide. Instead of owning the asset, the individual could rent the durable and still obtain

the flow of benefits from using the product. For the two products investigated empirically, such rental markets are normal. The data used in the empirical investigation includes 'ownership' whether by outright purchase or rental. In a perfectly competitive market, the rental cost in each period will be equal to the benefit received from using the asset in each period. Ultimately in equilibrium, the cost of acquisition of the asset would be equal to the sum of the discounted rental payments. If these rental payments were constant over time then the price of the durable could be replaced with the discounted rental payment. Of course the assumption of a perfectly competitive market may not be appropriate. In any case, since the empirical investigation is focusing upon explaining the diffusion of the stock of the durable, the cost of acquisition P_t can be used legitimately in the following empirical chapters.⁷

With a two period model and assuming myopic price expectations, the marginal buyer in period 1 will be of rank position such that the profitability condition holds,

$$h_1(Z) + h_2(Z)/(1+r) = P_1 \quad 4.3$$

Thus the critical value Z^* will be determined by economic variables, which in this particular case will be price P and the rate of discount r , so that implicitly the following can be written,

$$Z_t^* = g(P_t, r_t) \quad 4.4$$

As P and r change over time Z_t^* will change. As Z_t^* changes relative to $F(Z)$, ownership extends and the diffusion path is mapped out.

To be specific, in any period, the stock demand function will be,

$$X_t = M.(1 - F(Z_t^*)) \quad 4.5$$

where M is the size of the population and X_t is the cumulative stock of the new product owned at time t .

⁷ If one was interested in the consumption expenditures in any one period, then the value of the flow of services from the durable in that period would be relevant and consequently so would the rental cost.

4.3.3 Advertising in the Probit Model

It is now a fairly easy step to incorporate advertising into this framework. The most straightforward way is to allow advertising expenditures to increase the perceived flow benefit $h(Z)$ of every individual such that relative positions remain unchanged. This could occur because increasing advertising expenditures over time cause individuals to alter their preferences in favour of present as opposed to future consumption (Cowling 1982). However, although each individual's perceived benefit increases in response to advertising, this does not necessarily mean that it rises by a constant amount across individuals. Some consumers may be more prone to the advertising expenditures than others, for example, those individuals towards the top of the ranking.⁸ Incorporating such an idea would have the effect of capturing the diminishing marginal productivity of advertising messages as advertising is used to reach a continually less responsive audience (Simon 1970, Telser 1962).

So, with the introduction of advertising into the model equation 4.4 can be modified to allow that Z^*_t is a function of advertising expenditure A_t and thus write equation 4.6 as follows,

$$Z^*_t = g(P_t, r_t, A_t) \quad \frac{\partial Z^*_t}{\partial A_t} < 0 \quad \frac{\partial Z^*_t}{\partial P_t} > 0 \quad 4.6$$

As these economic variables change over time, so diffusion proceeds as progressively individuals lower down the given ranking have a characteristic level Z that exceeds the critical value Z^* as determined by equation 4.6 above.

There is another way in which advertising could be incorporated into the model. If advertising is assumed to affect the tastes of consumers, then these expenditures could be used to change the preferences of individuals in favour of some attribute inherent in

⁸ If the characteristic by which individuals are ranked is income, then differences in response across individuals can be explained by the message being more persuasive to those in the higher income bracket because as Galbraith (1967) argues, a greater proportion of their expenditure is devoted to luxury goods, desires for which are more psychological in nature and thus more prone to manipulative advertising. However the underlying assumption now is that an individual's flow benefit is positively related to their income level and this would need to be explained.

the new product. For example, referring back to Figures 1 and 2, if advertising is used to increase the relative preferences towards attribute CH2, then the compensation ratio for those individuals like consumer 1 will become smaller, although still greater than 1. For an individual like consumer 2, who is not totally satisfied with the attribute combination in the available good X and would prefer a specification such as new product W, the advertising would enhance this dissatisfaction with good X and this consumer's ratio will tend towards zero. This is shown in Figure 3 below.

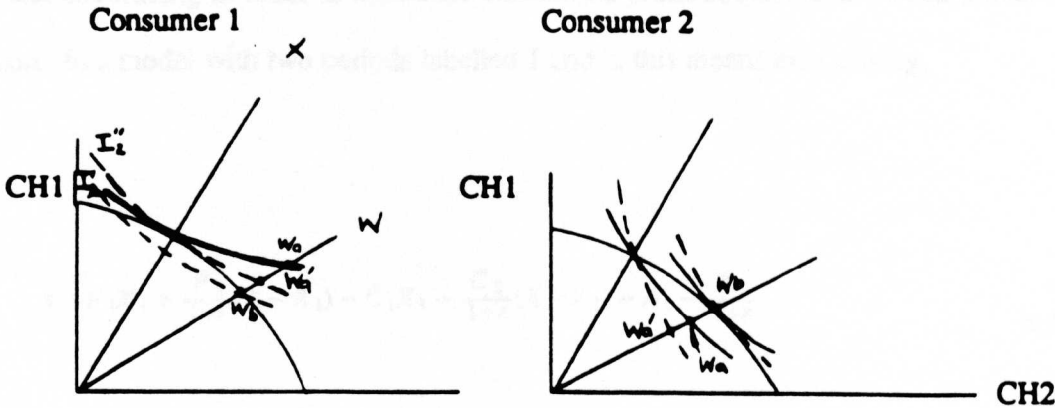


Figure 3

This has the effect of shifting the characteristic distribution $f(Z)$ to the right (as individuals are ranked from left to right according to the inverse of their compensation ratio).

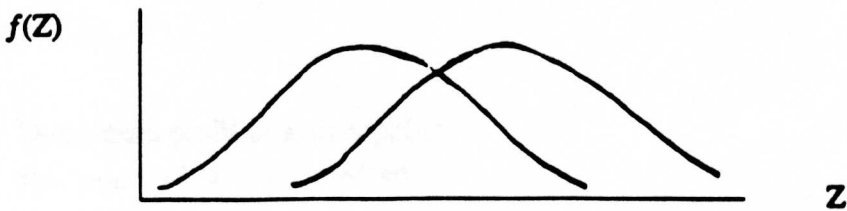


Figure 4

Effectively, the mean of this distribution becomes a function of advertising. Of course it will be impossible to distinguish empirically the route by which advertising enters the model. However this does not negate the exercise of trying to identify whether advertising does have a significant role to play in the diffusion process, it just means that

the precise manner in which it enters must be abandoned in favour of a more informal assessment. For the present, equation 4.6 is maintained as the working hypothesis.

4.3.4 Adding a Supply Sector; A Single Monopolist Supplier

Once a supply side is incorporated, price and advertising become endogenous to the model. To begin, assume a single monopolist supplier (however this will later be modified to include other competing producers). A monopolist will choose the level of price and advertising in order to maximise discounted profit subject to the stock demand function. In a model with two periods labelled 1 and 2, this means maximising,

$$\Pi = P_1 X_1 + \frac{P_2}{1+r} (X_2 - X_1) - C_1 X_1 - \frac{C_2}{1+r} (X_2 - X_1) - A_1 - \frac{A_2}{1+r} \quad 4.7$$

subject to,

$$X_1 = M.(1 - F(Z_1^*)) \text{ and } Z_1^* = g(P_1 A_1)$$

$$X_2 = M.(1 - F(Z_2^*)) \text{ and } Z_2^* = g(P_2 A_2)$$

4.8

where

Π = Discounted profit of a monopolist.

M = The size of the population

X_1 = Cumulated unit sales in period 1 (since by assumption owners purchase one unit only).

X_2 = Cumulated unit sales in period 2.

therefore

$(X_2 - X_1)$ = Quantity sold in period 2.

A_t = Advertising expenditures in time t .

C_1 = Marginal cost in period 2 (assumed constant).

P_t = Monopolist price in period t .

r = Discount rate.

(to simplify notation the exogenous rate of discount has been left out of the demand equations in order to concentrate upon the decision variables P and A).

Equation 4.7 can be expanded and rewritten in stock terms (given the relationship between stock and flow demand [$X_2 = (X_2 - X_1) + X_1$]) as follows;

$$\pi = P_1 X_1 - \frac{P_1}{1+r} X_1 + \frac{P_2}{1+r} X_2 - C_1 X_1 - \frac{C_2}{1+r} X_2 + \frac{C_2}{1+r} X_1 - A_1 - \frac{A_2}{1+r} \quad 4.7b$$

4.3.4.1 Rate of Extraction

The essence of the problem facing the supplier is the appropriate moment at which to extract a potential user from the finite population (there is obviously an analogy here between the optimal extraction rate of a finite mineral resource). Unlike the epidemic model, advertising expenditures in the first period do not produce a positive dynamic information externality to potentially offset the unambiguously negative early extraction effect. This early extraction effect is negative simply because there is a fixed pool of consumers. Given the assumption of unit purchase only, extracting a consumer now, as opposed to later, reduces the pool of remaining non owners in the next period.

Thus first period advertising expenditures serve to increase the number of users in the first period but at the expense of reducing the remaining stock of potential users available for extraction in the following period. Whether it is better to extract the marginal consumer in the first period rather than the second will depend upon the relative intertemporal discounted price cost margins available to the monopolist. So in

equilibrium, a monopolist will take first period extraction to the point at which the benefit of so doing equals the opportunity cost of such an action. This opportunity cost will take account of the possibilities that arise in this model for intertemporal price discrimination.

4.3.4.2 Intertemporal Price Discrimination

The feasibility of this intertemporal price discrimination arises due to some of the special features of the model. In any given period, consumers have differing perceptions about the total benefit from ownership commencing in that period, and assuming myopic price expectations a profit maximising monopolist can exploit these differences to charge individuals according to their perceived valuation of owning the good in a particular time period (the logical sequence of time prevents arbitrage as individuals who buy at a lower price in period 2 cannot resell to consumers in period 1). Of course if price expectations are not myopic but individuals expect prices to fall in the next period, then the possibilities for discrimination are reduced to some extent.

Theoretically, in a model having a continuous and infinite time horizon and myopic price expectations by consumers, the monopolist could appropriate the total consumer surplus by charging a different price to each individual in the population (Stoneman and Ireland 1985). However since the analysis here is restricted to a two period model with only one equilibrium price in each period, the opportunities for price discrimination are limited. This can be seen more clearly in the Figure below,

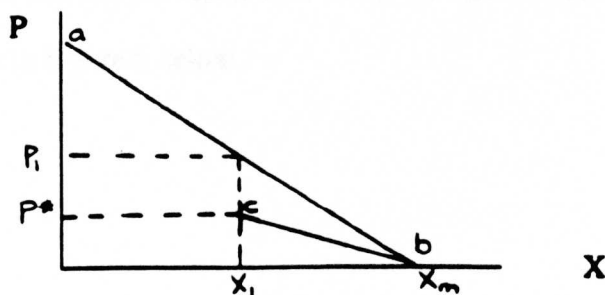


Figure 5

An individual who purchases the product in period 1, will obtain the perceived flow benefit of ownership in both period 1 and 2, that is, $h(Z) + h(Z)/(1+r)$. Curve ab shows the market cumulative stock demand function for the first period and the total discounted benefit $h(Z) + h(Z)/(1+r)$ is reflected in this curve, with the benefit reducing as X increases, that is, higher X being associated with lower values of Z and lower $h(Z)$. X_M is equal to the size of the population M (as only one unit is purchased) and would therefore represent a situation of complete diffusion amongst the population.

Assume X_1 units are purchased in period 1 at price P_1 . In period 2 each individual who then acquires the product will receive only the flow benefit for one period. Consequently the second period market stock demand function shown as cb in Figure 5 must lie below ab but still cross the horizontal axis at X_M . In period 2 the size of the remaining potential market is $X_1 X_M$. Unless price falls below P^* no further sales will occur in period 2 since the flow benefit and hence total benefit received by the $(X_1+1)^{th}$ individual will be too low relative to the cost of acquisition.⁹ Hence the price at which the $(X_1+1)^{th}$ unit can be sold in the second period depends upon the position in the ranking of the first period marginal buyer and therefore upon the total stock sold in the first period X_1 .

4.3.4.3 Advertising and the Stock Demand Curve

The effect of advertising can also be illustrated in this Figure. As advertising is assumed to increase each individual's perceived flow benefit and consequently the total benefit, this has the effect of rotating the market stock demand curve ab to position db as shown in Figure 6 below.

⁹ As explained above, this discontinuity arises due to the discrete two time period model employed.

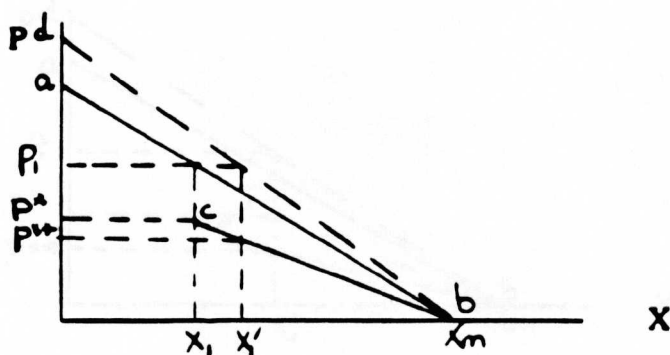


Figure 6

With the inclusion of advertising expenditures in the model, the number of owners in the first period given a price level P_1 is X'_1 . If individuals do not remember first period advertising, then those potential owners in the second period $X'_1 X_m$ will have a perceived flow benefit $h(Z)$ which is unchanged to that shown in the curve cb in Figure 6 above. Of course the difference is, that as a result of first period advertising, price must now fall below P^{**} (assuming that second period advertising is zero) if diffusion is to continue in the second period. Period 2 flow demand therefore depends upon lagged values as well as current values of the decision variables, price and advertising.

4.3.4.4 Advertising, Goodwill and the Market Stock Demand Curve

However it may be that potential buyers in the second period $X'_1 X_m$ remember the earlier advertising expenditures (Nerlove and Arrow (1962)). In which case the perceived flow benefit of individuals in the second period will also increase. So first period advertising will rotate cb to fb in addition to the movement of ab to db . Consequently the $(X'_1 + 1)^{th}$ unit can now be sold in the second period for a price above P^{**} (but below P'') even if advertising in the second period is zero. This is shown in Figure 7 below,

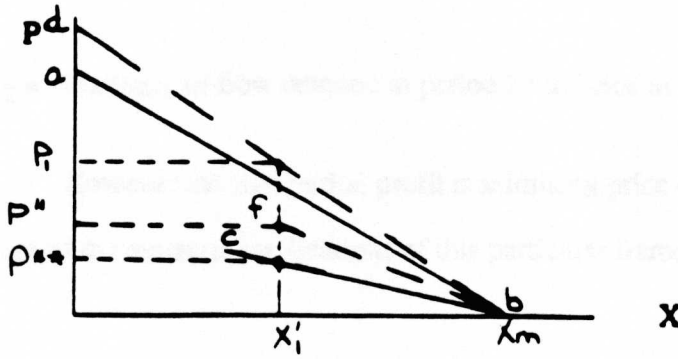


Figure 7

4.3.4.5 First Order Conditions; Price Cost Margin

Returning to the maximisation problem faced by the monopolist in equations 4.7b to 4.8 above, P_1 will be chosen (see appendix 4.1) such that in equilibrium,

$$\frac{\partial \pi}{\partial P_1} = P_1 \frac{\partial X_1}{\partial P_1} + X_1 = C_1 \frac{\partial X_1}{\partial P_1} - \frac{C_2}{1+r} \frac{\partial X_1}{\partial P_1} + \frac{P_2}{1+r} \frac{\partial X_1}{\partial P_1} \quad 4.9$$

The marginal revenue in the first period must be equal to first period marginal cost plus the opportunity cost of extracting the marginal consumer in the first period rather than in the second, that is, $(P_2 - C_2)/(1+r) \cdot \partial X_1 / \partial P_1$.

In period 2, the monopolist profit maximising price cost margin is the expected static result,

$$\frac{(P_2 - C_2)}{P_2} = \frac{-1}{\epsilon_{X_2 P_2}} \frac{(X_2 - X_1)}{X_2} \quad 4.10$$

where

$\epsilon_{X_2 P_2}$ = elasticity of stock demand in period 2 wrt price in period 2

and

$$\frac{-1}{\epsilon_{X_2 P_2}} \frac{(X_2 - X_1)}{X_2} = \frac{-1}{\eta_{Q_2 P_2}}$$

where

η_{q2p2} = elasticity of flow demand in period 2 wrt price in period 2

However the first period profit maximising price cost margin will explicitly take account of the dynamic implications of this particular framework as shown below,

$$\frac{(P_1 - C_1)}{P_1} - \frac{P_2}{P_1(1+r)} \frac{(P_2 - C_2)}{P_2} = \frac{-1}{\epsilon_{X1P1}} \quad 4.11$$

where

ϵ_{X1P1} = elasticity of stock demand in period 1 wrt price in period 1

Equation 4.11 indicates that a profit maximising monopolist will equate the difference in period 1 and 2 price cost margins to the inverse of the first period stock elasticity. In a static model, the price cost margin is known as the Lerner degree of monopoly power and shows that for a monopolist, the ability to raise price above the perfect competition level depends upon the flow demand elasticity. In this model the expression in equation 4.11 refers to the degree of price discrimination power (remember that the key issue in the probit model is the right time to extract the marginal buyer) and this depends upon the stock elasticity of demand in period 1.

4.3.4.6 Flow Demand Elasticities

Expressing the profit maximising price cost margin in flow rather than stock elasticities (and representing these by their absolute values, see Appendix 4.2) gives,

$$\frac{(P_1 - C_1)}{P_1} = \frac{1}{\eta_{q1p1}} + \frac{P_2}{P_1(1+r)} \frac{(P_2 - C_2)}{P_2} \frac{\eta_{q2p1}}{\eta_{q1p1}} \frac{(X_2 - X_1)}{X_1} \quad 4.12$$

$$\frac{(P_2 - C_2)}{P_2} = \frac{1}{\eta_{q2p2}} \quad 4.13$$

where

η_{q1p1} = elasticity of flow demand in period 1 wrt price in period 1

η_{q2p1} = elasticity of flow demand in period 2 wrt price in period 1

η_{q2p2} = elasticity of flow demand in period 2 wrt price in period 2

Equation 4.12 clearly shows the price cost margin in the first period derived from the probit model will be larger than that of a monopolist who considers the current period only and ignores the dynamic implications of his decisions, ie. the possibilities for intertemporal price discrimination.

4.3.4.7 Over Time

Over time, comparing the period 1 and 2 price cost margin in this particular framework, shows that the profit maximising price cost margin will fall provided that the flow price elasticities of demand are assumed constant so that $\eta_{q1p1} = \eta_{q2p2}$. Effectively the monopolist will be pursuing a 'price skimming strategy' to exploit the possibilities for intertemporal price discrimination.

4.3.4.8 Advertising Sales Ratio

Turning to the profit maximising advertising conditions (derived in Appendix 4.1 and 4.2), first period advertising expenditures will be such that,

$$\frac{\partial \pi}{\partial A_1} = P_1 \frac{\partial X_1}{\partial A_1} - C_1 \frac{\partial X_1}{\partial A_1} = 1 + \left(\frac{P_2 - C_2}{1+r} \right) \frac{\partial X_1}{\partial A_1} \quad 4.14$$

So the marginal revenue product of period 1 advertising must equal the marginal cost of such promotions plus the opportunity cost of extracting the marginal consumer by using advertising expenditures in period 1 rather than in period 2, that is , $(P_2 - C_2)/(1+r) \cdot \partial X_1 / \partial A_1$. The profit maximising advertising sales ratio will be,

$$\frac{A_1}{P_1 X_1} = \frac{\epsilon_{X_1 A_1}}{\epsilon_{X_1 P_1}} \quad 4.15$$

where

$\epsilon_{X_1 P_1}$ = elasticity of stock demand in period 1 wrt price in period 1

$\epsilon_{X_1 A_1}$ = elasticity of stock demand in period 1 wrt advertising in period 1

This on first sight, looks to be the Dorfman-Steiner condition. However the stock elasticity $\epsilon_{X_1 P_1}$ has been substituted for the degree of price discrimination over the two periods, so that 4.15 can be rewritten as,

$$\frac{A_1}{P_1 X_1} = \left[\frac{(P_1 - C_1)}{P_1} - \frac{P_2}{P_1(1+r)} \frac{(P_2 - C_2)}{P_2} \right] \epsilon_{X_1 A_1} \quad 4.16$$

4.3.4.9 Flow Elasticities of Demand

In order to highlight the differences arising in this particular model relative to the advertising sales ratios common in the literature, absolute values of flow elasticities rather than stock concepts are used below (assuming that $\eta_{q1A1} > 0$, $\eta_{q2A1} < 0$ and $\eta_{q1P1} < 0$, $\eta_{q2P1} > 0$),

$$\frac{A_1}{P_1 X_1} = \frac{\eta_{q1A1}}{\eta_{q1P1}} \left[1 + \frac{P_2}{P_1(1+r)} \frac{\eta_{q2P1}}{\eta_{q2P2}} \frac{(X_2 - X_1)}{X_1} \right] - \frac{P_2}{P_1(1+r)} \frac{\eta_{q2A1}}{\eta_{q2P2}} \frac{(X_2 - X_1)}{X_1} \quad 4.17$$

$$\frac{A_2}{P_2(X_2 - X_1)} = \frac{\eta_{q2A2}}{\eta_{q2P2}} \quad 4.18$$

where

η_{q1A1} = the elasticity of flow demand q in period 1 wrt advertising in period 1.

$\eta_{q|P_t}$ = the elasticity of flow demand q in period t wrt price in period t .

It is the first period results that are of interest. Equation 4.17 contains two terms additional to the Dorfman Steiner condition. Define ψ as,

$$\psi = \frac{P_2}{P_1(1+r)} \frac{\eta_{q2P1}}{\eta_{q2P2}} \frac{(X_2 - X_1)}{X_1} \frac{\eta_{q1A1}}{\eta_{q1P1}} - \frac{P_2}{P_1(1+r)} \frac{\eta_{q2A1}}{\eta_{q2P2}} \frac{(X_2 - X_1)}{X_1}$$

4.19

These new terms within the profit maximising advertising sales ratio in period 1 are a consequence of the long run implications of first period decisions. The effect of changes in price or advertising in the first period, consists of two elements. Firstly there is the early extraction effect. Transforming a potential owner into an actual owner in the current period, reduces the number of potential consumers in future periods (hence the assumption that η_{q1A1} is negative and η_{q1P1} is positive above). Secondly, there is an opportunity cost to this early extraction, because of the intertemporal price discrimination possibilities.

Consequently, the advertising sales ratio derived in this particular framework will be greater than the Dorfman Steiner condition provided that $\psi > 0$. This requires that the following condition holds,

$$\left| \frac{\eta_{q1A1}}{\eta_{q1P1}} \right| > \left| \frac{\eta_{q2A1}}{\eta_{q2P1}} \right|$$

4.20

Thus the ratio of the responsiveness of demand to the current decision variables must be larger than the ratio of the responsiveness of demand to the lagged decision

variables. In other words, the negative early extraction effect must be outweighed by the relative effectiveness of the current variables.

Within this model, if the simplifying assumption is made that the current flow elasticities are equal so that,

$$\eta_{q1A1} = \eta_{q2A2} \text{ and } \eta_{q1P1} = \eta_{q2P2}$$

then provided that $\psi > 0$, the profit maximising advertising intensity for a monopolist will fall over time.

These dynamic implications arise as a result of analysing stock demand for a new consumer durable. Flow demand in any one period will be dependent upon the present level of diffusion of the product, as this limits the pool of non owners remaining in the population. Consequently a flow demand function can be derived showing the quantity that can be sold as a function of present price and advertising expenditure, given the existing level of ownership. Existing ownership will in turn have been affected by past pricing and advertising decisions and so lagged values will impinge upon current flow demand indirectly, via the cumulative stock sold to date. This route will be referred to as the stock effect.

4.2.4.10 The Effects of Past Advertising

However this is not the only route by which lagged advertising can affect current flow demand. If, as explained in Figure 7 above, individuals remember earlier advertising, then even with zero current advertising, an individuals perceived flow benefit will be higher than otherwise due to the lagged effect of promotions undertaken in previous periods. This will be in addition to the stock effect and will be referred to as the goodwill effect (as advertising expenditures are adding to a stock of goodwill as suggested by Nerlove and Arrow 1962).

This additional dynamic role of advertising therefore modifies the basic model as follows,

$$Z_t^* = j(P_t, G_t, r_t) \quad 4.21$$

where

$$G_t = A_t + (1-\delta)A_{t-1} \quad 4.22$$

Now the profit maximising results with respect to the advertising decision variable only (derived in Appendix 4.3) and using absolute flow elasticities are as follows,

$$\frac{G_1}{P_1 X_1} = \frac{\eta_{q1G1}}{\eta_{q1P1}} \left[\frac{1+r}{r-1+2\delta} + \frac{\eta_{q2P1}}{\eta_{q2P2}} \frac{P_2}{P_1} \frac{(X_2-X_1)}{X_1} \frac{1}{r-1+2\delta} \right] + / - \frac{\eta_{q2G1}}{\eta_{q2P2}} \frac{P_2}{P_1} \frac{(X_2-X_1)}{X_1} \frac{1}{r-1+2\delta} \quad 4.23$$

$$\frac{G_2}{P_2(X_2-X_1)} = \frac{\eta_{q2G2}}{\eta_{q2P2}} \quad 4.24$$

where

η_{qtGt} = the elasticity of flow demand q in period t wrt the stock of advertising goodwill in period t .

If the rate of decay of the advertising stock δ is 1, then the results obviously collapse to those in equation 4.17 above because advertising messages are completely forgotten within the current period. Thus referring back to Figure 7 the period 2 market stock demand curve will not rotate clockwise to fb unless period 2 advertising is undertaken.

If $\delta < 1$, then some of the previous advertising messages are remembered by the non owners in the next period, causing them to increase their perceived flow benefit of

ownership $h(Z)$. Consequently, η_{q2G1} is not unambiguously negative because it is composed of two conflicting elements, this introduces the uncertainty into the sign of the second and third terms in equation 4.23 above. Increasing period 1 advertising (and hence G_1) increases X_1 thereby inducing the negative early extraction effect. However the stock of goodwill is also increased and this has a positive effect on period 2 flow demand. This can be seen more clearly in the Figure below,

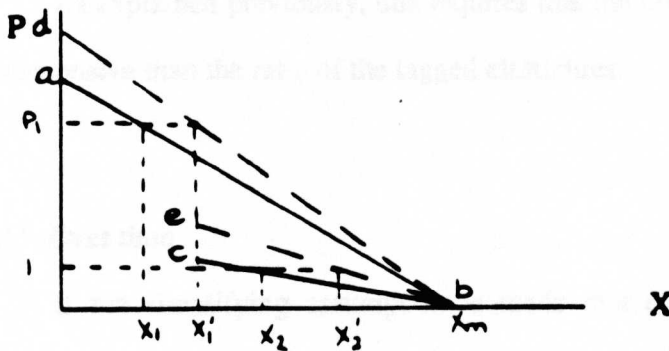


Figure 8

Curves ab and cb represent the stock demand functions in period 1 and 2 respectively when advertising expenditures are zero. Positive advertising expenditures in period 1 rotate the stock demand curve ab to db . However, in addition, this earlier advertising is remembered by the population of remaining potential buyers in period 2, thus increasing their perceived flow benefit in that period 2 even if advertising expenditures in period 2 are zero. This is the N-A goodwill effect and rotates the stock demand curve cb to eb . $X'_1 - X_1$ is the increased early extraction due to period 1 advertising. $X'_2 - X_2$ is the goodwill effect of period 1 advertising. Provided that the goodwill effect $X'_2 - X_2$ outweighs the negative extraction effect $X'_1 - X_1$ then η_{q2g1} will be positive, thus the goodwill sales ratio derived from the probit based demand equation will be greater than the usual Nerlove-Arrow condition. This implicitly enhances the benefit of period 1 advertising.¹⁰

¹⁰ A further condition is required that $r > 1 - 2\delta$. This has already been explained in the previous chapter.

If however, the overall dynamic effect of G_1 on period 2 flow demand $X_2 - X_1$ is negative, so that the stock effect is offsetting the goodwill effect then the advertising intensity in this model will only be larger than the Nerlove Arrow condition provided that the following holds,

$$\left| \frac{\eta_{q1G1}}{\eta_{q1P1}} \right| > \left| \frac{\eta_{q2G1}}{\eta_{q2P1}} \right| \quad 4.25$$

As explained previously, this requires that the ratio of the current elasticities be more responsive than the ratio of the lagged elasticities.

4.3.4.11 Over time

If the simplifying assumption is made that current elasticities are constant ($\eta_{q1G1} = \eta_{q2G2}$ and $\eta_{q1P1} = \eta_{q2P2}$), then the profit maximising advertising sales ratio will decline over time provided that,

$$1+r > \frac{P_2}{P_1} \frac{(X_2 - X_1)}{X_1} \left(\left| \frac{\eta_{q2G1}}{\eta_G} \right| - \left| \frac{\eta_{q2P1}}{\eta_P} \right| \right) \quad 4.26$$

The LHS of equation 4.26 is the time discount factor, so a falling ratio requires this to be larger than the net result of the relative intertemporal advertising and price effects. The time factor is a consequence of preferring revenues today rather than tomorrow, yet the monopolist needs to weigh this against the additional intertemporal features of this model, namely the early extraction effect and price discrimination opportunities.

4.3.4.12 Summary

To summarise, the main feature of the probit model analysed in this chapter, is the finite nature of the population of potential buyers. A monopolist will need to take account of the intertemporal implications of his decisions, which arise from analysing stock demand for new consumer durables in a probit model. Current flow demand will depend not only upon the current decision variables (price and advertising) but also on the existing level of diffusion. Consequently past levels of the decision variables will impinge upon the current flow demand function. Given myopic price expectations by consumers, the monopolist has the opportunity for intertemporal price discrimination in this probit model. In a static model, a monopolist's profit maximising price cost margin (degree of monopoly power) is equal to the inverse of the elasticity of flow demand with respect to price. In the model presented in this chapter, the profit maximising condition for a monopolist is that the degree of intertemporal price discrimination (ie. the difference in the discounted price cost margins in the two periods) is equal to the inverse of the elasticity of stock demand in period 1 with respect to price in period 1. Using current flow elasticities instead, it was shown that the first period price cost margin for a monopolist in this probit model, would be larger than that for a monopolist who did not consider the dynamic implications of his decision.

Compared to the Dorfman Steiner condition, the profit maximising advertising sales ratio for a monopolist in the probit model included two additional terms which took account of the dynamic implications of early extraction and intertemporal price discrimination. These additional terms would be positive (and so the advertising sales ratio larger than that suggested by D-S) provided that the ratio of the responsiveness of current flow demand to the current decision variables was larger than the ratio of the responsiveness of flow demand to the lagged decision variables ie.

$$\left| \frac{\eta_{q1A1}}{\eta_{q1P1}} \right| > \left| \frac{\eta_{q2A1}}{\eta_{q2P1}} \right| \quad 4.20$$

If this condition holds then the negative early extraction effect is outweighed by the relative effectiveness of current variables on demand. If the reverse was true then the

advertising sales ratio would be smaller than that suggested by the D-S condition. Over time, assuming that the current demand elasticities are constant and that equation 4.20 holds then the advertising intensity in this model will fall.

The inclusion of lagged advertising variables in the current flow demand function arose due to the special features of the analysis using the probit model. However, in addition lagged advertising could have an effect on current demand through the stock of goodwill concept of Nerlove and Arrow (1962). So even if no advertising is undertaken in future periods, individuals will still remember past promotions and so the effect on the perceived flow benefit would be lasting (although at a decaying rate). Unlike the probit model in which advertising did not add to a stock of goodwill, the effect of advertising on period 2 flow demand is ambiguous. In the model without goodwill, first period advertising has a negative impact on future sales due to the early extraction effect.¹¹ In the N-A model, without recognising the special features of the probit model, the effect of past advertising on flow demand would be unambiguously positive. Hence in the probit model with goodwill effects the net outcome is ambiguous. Provided that the goodwill effect outweighs the negative early extraction effect, the goodwill sales ratio in the probit model will be larger than that suggested by the N-A condition. If the negative extraction effect dominates to such an extent that it outweighs the effect of current variables on current demand plus the positive goodwill effect, then the profit maximising goodwill sales ratio will be lower than that suggested by the N-A condition. Over time, if the current demand elasticities are assumed constant, then the goodwill sales ratio will decline provided that the time discount factor is larger than the net result of the relative intertemporal advertising and price effects.

4.3.5 The Probit Model with More than One Supplier

So far the analysis has centred upon a monopolist supplier of the new consumer durable. However this assumption will now be relaxed to allow for more than one supplier of the product. The existence of heterogeneous products amongst suppliers,

¹¹ Unlike the epidemic model, there is no compensating positive information externality.

causes problems in the probit model, as this framework uses the concept that individuals in the population are ranked according to a characteristic Z which was related to an individual's relative preference for the new product. For simplicity, the distribution of the ranking will be assumed to refer to the generic product type, for example a colour television receiver rather than for a particular brand of colour receiver. If this assumption was not made, then each firm would face a unique distribution and this would present difficulties in the aggregation procedures necessary to explain the diffusion of the generic product type.

To recap, intra product heterogeneity is not being addressed explicitly. Whilst recognising that products can differ once the monopolist supplier assumption is relaxed, the analysis here will adopt the approach suggested by Cubbin (1974) ie. invoke a symmetry rule such that only one price exists in industry equilibrium.

Likewise, advertising by individual firms is assumed homogeneous (the limitations of this have already been discussed in Chapter 3). So it is assumed that,

- i) total industry advertising, the summation of individual firms' advertising expenditures will determine total industry stock demand.
- ii) each firm's market share will depend upon their share of total advertising spend and such expenditures will be equally effective, thus quality differences of advertising campaigns are ignored.

Total industry advertising is assumed to determine total industry stock demand because it acts upon the flow benefit perceived by all individuals. Thus each firm's advertising is additive in its effect upon the identity of the marginal buyer. Therefore the larger the volume of advertising the greater will be the total benefit of ownership perceived by all individuals in the population. This could be explained as a variant of the 'demonstration effect'. As more suppliers of the good appear on the market, the intensity of the advertising persuades individuals to increase their valuation of this new good

relative to the old substitute. Alternatively, advertising could contain information about some feature of the new product. The more advertising undertaken, the more likely it is that a variety of features are highlighted, so this accumulation of information may increase a consumer's valuation of the product in an additive fashion.

The essential features of the probit model are the finite stock of potential consumers and the implications of intertemporal price discrimination for the optimal extraction rate. Should a monopolist decide to postpone extraction of an individual, then without the threat of entry, the sole producer can be secure in the knowledge that this individual will be available for extraction in the next period. However once at least one more supplier or potential supplier exists, then the effect will be to potentially increase the profit maximising extraction rate. This arises due to the fear that existing rivals may poach the consumer first. There will be a race to extract the consumer from the finite population and unlike the epidemic model introduced in the previous chapter, there is no information externality to potentially offset this negative factor.

Of course oligopolistic suppliers may be encouraged to collude, either implicitly or explicitly. The stability of their agreement depends upon the intertemporal trade-offs involved. The gains from cheating must not be outweighed by the subsequent loss from retaliatory action and the breakdown in the collusive agreement.

By extracting the marginal buyer in period 1, the oligopolist obtains the full benefit of his action. However the dynamic consequences, the negative extraction effect, will be borne by all the suppliers in the following period. For the individual firm, the decision about the optimal time to extract a consumer will obviously depend upon the benefit and opportunity cost of his decisions. The benefit in the case of advertising, will include an increase in current demand plus an increased share of the expanded market. Given the assumption of zero conjectural variations, each firm believes that any change in price or advertising will not prompt a reaction from rivals. Consequently the individual firm will expect to reap all of the benefit of its first period decisions.

The opportunity cost of such action will be the discounted profit that would have been obtainable from extracting this marginal buyer in the next period rather than currently. Unlike the model with only one supplier, an oligopolistic firm will consider that there are $n-1$ other firms in the next period who will share the burden of this early extraction. If all firms are acting with Cournot type behaviour, then in equilibrium an individual firm is likely to choose a lower price and advertise more heavily than a monopolist. Hence the diffusion rate will be faster in this probit framework when the supply sector is modified to incorporate rival suppliers.

4.3.5.3 First Order Conditions

The intuitive reasoning can be seen more clearly in the first order conditions. These expressions are derived in appendix 4.4. An oligopolist will choose his advertising expenditures a_{it} and stock x_{it} in order to maximise discounted profits π_i

$$\pi_i = P_1 s_{i1} X_1 - c_{i1} s_{i1} X_1 + \frac{P_2}{1+r} s_{i2} X_2 - \frac{P_2}{1+r} s_{i2} X_1 - \frac{c_{i2}}{1+r} s_{i2} X_2 + \frac{c_{i2}}{1+r} s_{i2} X_1 - a_{i1} - \frac{a_{i2}}{1+r} \quad 4.27$$

subject to

$$X_1 = N \left[1 - F(J_1(P_1, A_1)) \right] \quad X_2 = N \left[1 - F(J_2(P_2, A_2)) \right] \quad 4.28$$

where

$$X_t = \sum_{i=1}^{i=n} x_{it} \quad A_t = \sum_{i=1}^{i=n} a_{it}$$

Marginal cost c_{it} is assumed constant within a time period but can differ across time. Firms are assumed to adopt zero conjectural variations behaviour, so,

$$\frac{\partial \pi_i}{\partial x_{i1}} = (P_1 - c_{i1}) s_{i1} + (P_1 - c_{i1}) X_1 \frac{\partial s_{i1}}{\partial x_{i1}} + s_{i1} X_1 \frac{\partial P_1}{\partial x_{i1}} - \left(\frac{P_2 - c_{i2}}{1+r} \right) s_{i2} = 0 \quad 4.29$$

The first three terms in equation 4.29 are the usual first order terms found for a Cournot quantity setting oligopolist in a static framework. The final term is the opportunity cost associated with changing first period output, of which the individual firm bears the second period share, that is, $s_{i2} \cdot (P_2 - c_{i2}) / (1+r)$.

Assuming there are n symmetric firms, each facing the same cost conditions and holding the same Cournot conjectures about the behaviour of rivals and summing across n to obtain the profit maximising industry price cost margin,

$$\frac{(P_1 - C_1)}{P_1} - \frac{1}{n} \frac{P_2}{P_1(1+r)} \frac{(P_2 - C_2)}{P_2} = - \frac{1}{\epsilon_{x1P1} n} \quad 4.30$$

Thus the degree of monopoly in the first period less $(1/n)^{\text{th}}$ of the second period discounted degree of monopoly is set equal to the individual firms stock elasticity in equilibrium.¹² For a symmetric Cournot quantity setting firm in a static environment, the industry and individual price cost margin will be,

$$\frac{(P_1 - C_1)}{P_1} = - \frac{1}{\eta_{x1P1} n} \quad 4.31$$

However in this particular probit model, a firm must take account of the negative early extraction effect, the cost of which is shared by all suppliers in the second period. The first period price cost margin is still larger in this particular framework than would be the case for the equilibrium condition derived for an oligopolist within a static environment as in equation 4.31 above. Compared to the single supplier who recognises the dynamic implications of this probit based framework, a larger equilibrium price cost margin cannot be rigorously proven from the mathematical express due to the endogeneity of the discounted relative price element contained within the second term of the LHS of equation 4.30 above. However it was argued that this was likely to be the outcome due to the incentive to race to extract the marginal buyer as part of the cost of this action will be passed on to rivals in the next period.

¹². With symmetric firms and Cournot behaviour, this is equivalent to $(1/n)^{\text{th}}$ of industry price demand elasticity.

Turning to the first period advertising decision, a profit maximising firm will in equilibrium advertise up to the point at which,

$$\frac{\partial \pi_i}{\partial a_{i1}} = (P_1 - c_{i1})s_{i1} \frac{\partial X_1}{\partial A_1} + (P_1 - c_{i1}) \frac{X_1}{A_1} (1 - s_{i1}) - \left[P_2 - c_{i2} \frac{1}{1+r} \right] s_{i2} \frac{\partial X_1}{\partial A_1} = 1 \quad 4.32$$

The first two terms refer to the usual current expansionary industry demand and the market share effects. The third term captures the opportunity cost involved in extracting the marginal buyer in period 1 rather than in the next period. However this opportunity cost will be distributed amongst all firms, therefore the second period market share s_{i2} is the appropriate factor for consideration by the individual firm. Further manipulation and aggregation across all firms gives the following profit maximising first period industry advertising sales ratio,¹³

$$\frac{(P_1 - C_1)}{P_1} \left[1 - \frac{1}{n} \right] + \left[\frac{(P_1 - C_1)}{P_1} - \frac{(P_2 - C_2)}{P_2} \frac{P_2}{P_1(1+r)} \right] \frac{e_{X1A1}}{n} = \frac{A_1}{P_1 X_1} \quad 4.33$$

The first term in equation 4.33 above refers to the distributional effect of advertising on market share. The second term captures the intertemporal price discrimination possibilities. Substituting for the profit maximising first and second period price cost margins gives,

$$\frac{A_1}{P_1 X_1} = - \frac{n-1 + e_{X1A1}}{e_{X1P1} n^2} + (e_{X1A1} - 1) \left[\frac{n-1}{e_{X2P2} n^2} \right] \left[\frac{P_2}{P_1(1+r)} \frac{(X_2 - X_1)}{X_1} \right] \quad 4.34$$

As shown in the previous chapter, the condition derived for a symmetric quantity setting firm adopting Cournot behaviour within a static framework is,

¹³ As all firms are assumed symmetric then the marginal cost for all firms within a period will be equal, that is, C_t .

$$\frac{A}{P.X} = \frac{\eta_A + n-1}{n^2.\eta_P} \quad 4.35$$

Compared to equation 4.35, the condition derived within the probit based demand diffusion model, has an additional term which can be positive or negative. This is analogous to the monopoly result derived in equation 4.16 and the dynamic profit maximising ratio will be larger than the static condition provided that the negative stock effect consideration is outweighed by the relative responsiveness of the current elasticities (refer to equation 4.20 for the precise condition).

Summary

When allowing for more than one supplier in this particular probit model, the main implication is that the opportunity cost of early extraction is shared by all the $n-1$ firms in the next period. Intuitively, this would tend to promote a 'race to extract' the consumers from the finite population in earlier periods than would have been the case for a monopolist supplier. Hence the expectation of a lower price cost margin and larger advertising sales ratio in an oligopolistic industry as compared to a monopoly one. However this result could not be proved rigorously due to the endogeneity of the relative price term in the profit maximising conditions.

4.4 EPIDEMIC VERSES PROBIT MODEL

Although a strict comparison between the profit maximising sales ratios derived from an epidemic and probit based demand diffusion model is not legitimate, it is interesting to consider the differences informally. Within an epidemic framework, the existence of the information externality gives rise to the possibility of a positive net dynamic effect, whereas in the probit based model, the dynamic effect is unambiguously

negative.¹⁴ Consequently, the profit maximising advertising sales ratio is likely to be larger in the epidemic model provided that in that model,

$$\left(\frac{\partial X_2}{\partial X_1} - 1 \right) > -1 \quad 4.36$$

When this overall dynamic owner externality equals -1, then the situation is similar to the probit based framework where extracting the marginal buyer in period 1 decreases the potential population in the next period by one. Provided that the information externality compensates for this negative early extraction effect either partially or fully, then *ceteris paribus*, the advertising intensity will be larger when the demand diffusion equation is of an epidemic based nature. Of course this conclusion must be treated with caution because as indicated above the mathematical expressions cannot be strictly compared since, unlike in the probit based model, price is exogenous in the epidemic framework, and the advertising elasticities within each framework are unlikely to be the same.

¹⁴ The possibilities of advertising having a positive dynamic effect by adding to a stock of goodwill as suggested by Nerlove and Arrow are being ignored here. Recognition of this additional dynamic role will serve to emphasise the positive dynamic effect within the epidemic model and give rise to ambiguity in the probit based model.

APPENDIX 4.1

(For a full description of the variables, refer to page 104 in chapter 4).

A monopolist will maximise the following profit function (in stock terms)

$$\pi = P_1 X_1 - \frac{P_2}{1+r} X_1 + \frac{P_2}{1+r} X_2 - C_1 X_1 - \frac{C_2}{1+r} X_2 + \frac{C_2}{1+r} X_1 - A_1 - \frac{A_2}{1+r}$$

subject to the following stock demand functions which are based upon a probit demand diffusion model as described in section 4.3 of chapter 4.

$$X_1 = N\left[1 - F(J_1(P_1, A_1))\right] \quad X_2 = N\left[1 - F(J_2(P_2, A_2))\right]$$

$$\frac{\partial \pi}{\partial P_1} = P_1 \frac{\partial X_1}{\partial P_1} + X_1 - \frac{P_2}{1+r} \frac{\partial X_1}{\partial P_1} - C_1 \frac{\partial X_1}{\partial P_1} + \frac{C_2}{1+r} \frac{\partial X_1}{\partial P_1} = 0$$

$$\left[P_1 - \frac{P_2}{1+r} - C_1 + \frac{C_2}{1+r} \right] \frac{\partial X_1}{\partial P_1} = -X_1$$

divide through by X_1 and multiply the LHS by $\frac{P_1}{P_1}$

$$\frac{(P_1 - C_1)}{P_1} - \frac{P_2}{P_1(1+r)} \frac{(P_2 - C_2)}{P_2} = - \frac{1}{\epsilon_{X1P1}} \quad (1)$$

where $\epsilon_{X1P1} = \frac{\partial X_1}{\partial P_1} \frac{P_1}{X_1}$

$$\frac{\partial \pi}{\partial P_2} = \frac{P_2}{1+r} \frac{\partial X_2}{\partial P_2} + \frac{X_2}{1+r} - \frac{X_1}{1+r} - \frac{C_2}{1+r} \frac{\partial X_2}{\partial P_2} = 0$$

$$\left[\frac{P_2 - C_2}{1+r} \right] \frac{\partial X_2}{\partial P_2} = - \frac{X_2}{1+r} + \frac{X_1}{1+r}$$

$$\frac{(P_2 - C_2)}{P_2} = - \left[\frac{(X_2 - X_1)}{X_2} \right] \frac{1}{\epsilon_{X2P2}} \quad (2)$$

where $\epsilon_{X_2 P_2} = \frac{\partial X_2}{\partial P_2} \frac{P_2}{X_2}$

$$\frac{\partial \pi}{\partial A_1} = P_1 \frac{\partial X_1}{\partial A_1} - \frac{P_2}{1+r} \frac{\partial X_1}{\partial A_1} - C_1 \frac{\partial X_1}{\partial A_1} + \frac{C_2}{1+r} \frac{\partial X_1}{\partial A_1} = 1$$

$$\left(P_1 - C_1 - \frac{P_2}{1+r} + \frac{C_2}{1+r} \right) \frac{\partial X_1}{\partial A_1} = 1$$

$$\frac{A_1}{P_1 X_1} = \left(\frac{(P_1 - C_1)}{P_1} - \frac{P_2}{P_1(1+r)} \frac{(P_2 - C_2)}{P_2} \right) \epsilon_{X_1 A_1}$$

and substitute from equ 1

$$\frac{A_1}{P_1 X_1} = - \frac{\epsilon_{X_1 A_1}}{\epsilon_{X_1 P_1}} \quad (3)$$

where $\epsilon_{X_1 A_1} = \frac{\partial X_1}{\partial A_1} \frac{A_1}{X_1}$

$$\frac{\partial \pi}{\partial A_2} = \frac{P_2}{1+r} \frac{\partial X_2}{\partial A_2} - \frac{C_2}{1+r} \frac{\partial X_2}{\partial A_2} = \frac{1}{1+r}$$

$$(P_2 - C_2) \frac{\partial X_2}{\partial A_2} = 1$$

$$\frac{A_2}{P_2 X_2} = \frac{(P_2 - C_2)}{P_2} \epsilon_{X_2 A_2}$$

and substitute from equ 2

$$\frac{A_2}{P_2 X_2} = - \frac{(X_2 - X_1)}{X_2} \frac{\epsilon_{X_2 A_2}}{\epsilon_{X_2 P_2}}$$

where $\epsilon_{X_2 A_2} = \frac{\partial X_2}{\partial A_2} \frac{A_2}{X_2}$

$$\frac{A_2}{P_2(X_2 - X_1)} = - \frac{\epsilon_{X_2 A_2}}{\epsilon_{X_2 P_2}}$$

APPENDIX 4.2

$$\pi = P_1 X_1 + \frac{P_2}{1+r} (X_2 - X_1) - C_1 X_1 - \frac{C_2}{1+r} (X_2 - X_1) - A_1 - \frac{A_2}{1+r}$$

$$X_1 = N \left[1 - F(J_1(A_1, P_1)) \right] \quad \begin{array}{l} X_1 = \text{Cumulated unit sales in period} \\ X_2 = \text{Cumulated unit sales in period} \end{array}$$

∴ $(X_2 - X_1) = \text{Quantity sold in period 2}$

$$(X_2 - X_1) = N \left[F(J_1(A_1, P_1)) - F(J_2(P_2, A_2)) \right]$$

$$\frac{\partial \pi}{\partial P_1} = P_1 \frac{\partial X_1}{\partial P_1} + X_1 + \frac{P_2}{1+r} \frac{\partial (X_2 - X_1)}{\partial P_1} - C_1 \frac{\partial X_1}{\partial P_1} - \frac{C_2}{1+r} \frac{\partial (X_2 - X_1)}{\partial P_1} = 0$$

$$(P_1 - C_1) \frac{\partial X_1}{\partial P_1} + \frac{(P_2 - C_2)}{1+r} \frac{\partial (X_2 - X_1)}{\partial P_1} = -X_1$$

$$\frac{(P_1 - C_1)}{P_1} = -\frac{1}{\eta_{q1P1}} - \frac{P_2}{P_1(1+r)} \frac{(P_2 - C_2)}{P_2} \frac{\eta_{q2P1}}{\eta_{q1P1}} \frac{(X_2 - X_1)}{X_1} \quad (1)$$

where

$$\eta_{q1P1} = \frac{\partial X_1}{\partial P_1} \frac{P_1}{X_1} \quad , \quad \eta_{q2P1} = \frac{\partial (X_2 - X_1)}{\partial P_1} \frac{P_1}{(X_2 - X_1)}$$

$$\frac{\partial \pi}{\partial P_2} = \frac{P_2}{1+r} \frac{\partial (X_2 - X_1)}{\partial P_2} + \frac{(X_2 - X_1)}{1+r} - \frac{C_2}{1+r} \frac{\partial (X_2 - X_1)}{\partial P_2} = 0$$

$$(P_2 - C_2) \frac{\partial (X_2 - X_1)}{\partial P_2} = -(X_2 - X_1)$$

$$\frac{(P_2 - C_2)}{P_2} = -\frac{1}{\eta_{q2p2}}$$

2

$$\text{where } \eta_{q2p2} = \frac{\partial(X_2 - X_1)}{\partial P_2} \frac{P_2}{(X_2 - X_1)}$$

$$\frac{\partial \pi}{\partial A_1} = P_1 \frac{\partial X_1}{\partial A_1} + \frac{P_2}{1+r} \frac{\partial(X_2 - X_1)}{\partial A_1} - C_1 \frac{\partial X_1}{\partial A_1} - \frac{C_2}{1+r} \frac{\partial(X_2 - X_1)}{\partial A_1} = 1$$

$$(P_1 - C_1) \frac{\partial X_1}{\partial A_1} + \frac{(P_2 - C_2)}{1+r} \frac{\partial(X_2 - X_1)}{\partial A_1} = 1$$

$$\frac{A_1}{P_1 X_1} = \frac{(P_1 - C_1)}{P_1} \eta_{q1A1} + \frac{P_2}{P_1(1+r)} \frac{(P_2 - C_2)}{P_2} \eta_{q2A1} \frac{(X_2 - X_1)}{X_1}$$

substitute from equ 1 and equ 2 for price cost margins

$$\frac{A_1}{P_1 X_1} =$$

$$-\frac{\eta_{q1A1}}{\eta_{q1P1}} \left[1 - \frac{P_2}{P_1(1+r)} \frac{\eta_{q2p1}}{\eta_{q2p2}} \frac{(X_2 - X_1)}{X_1} \right] - \frac{P_2}{P_1(1+r)} \frac{\eta_{q2A1}}{\eta_{q2p2}} \frac{(X_2 - X_1)}{X_1} \quad (3)$$

where

$$\eta_{q1A1} = \frac{\partial X_1}{\partial A_1} \frac{A_1}{X_1}, \quad \eta_{q2A1} = \frac{\partial(X_2 - X_1)}{\partial A_1} \frac{A_1}{(X_2 - X_1)}, \quad \eta_{q2A2} = \frac{\partial(X_2 - X_1)}{\partial A_2} \frac{A_2}{(X_2 - X_1)}$$

$$\frac{\partial \pi}{\partial A_2} = \frac{P_2}{1+r} \frac{\partial(X_2 - X_1)}{\partial A_2} - \frac{C_2}{1+r} \frac{\partial(X_2 - X_1)}{\partial A_2} = \frac{1}{1+r}$$

$$\frac{A_2}{P_2(X_2 - X_1)} = \frac{(P_2 - C_2)}{P_2} \eta_{q2A2}$$

substitute for the price cost margin from equ 2

$$\frac{A_2}{P_2(X_2 - X_1)} = - \frac{\eta_{q_2 p_2}}{\eta_{q_2 p_2}}$$

APPENDIX 4.3

$$\pi = P_1 X_1 + \frac{P_2}{1+r} (X_2 - X_1) - C_1 X_1 - \frac{C_2}{1+r} (X_2 - X_1) - G_1 + \frac{(1-\delta)}{(1+r)} G_1 - \frac{G_2}{1+r}$$

$$X_1 = N \left[1 - F(J_1(P_1, G_1)) \right]$$

$$(X_2 - X_1) = N \left[F(J_1(P_1, G_1)) - F(J_2(P_2, G_2)) \right]$$

$$G_1 = A_1$$

$$G_2 = A_2 + (1-\delta)A_1$$

$$\frac{\partial \pi}{\partial P_1} = P_1 \frac{\partial X_1}{\partial P_1} + X_1 + \frac{P_2}{1+r} \frac{\partial (X_2 - X_1)}{\partial P_1} - C_1 \frac{\partial X_1}{\partial P_1} - \frac{C_2}{1+r} \frac{\partial (X_2 - X_1)}{\partial P_1} = 0$$

$$(P_1 - C_1) \frac{\partial X_1}{\partial P_1} + \frac{(P_2 - C_2)}{1+r} \frac{\partial (X_2 - X_1)}{\partial P_1} = -X_1$$

$$\frac{(P_1 - C_1)}{P_1} = -\frac{1}{\eta_{q1P1}} - \frac{P_2}{P_1(1+r)} \frac{(P_2 - C_2)}{P_2} \frac{\eta_{q2P1}}{\eta_{q1P1}} \frac{(X_2 - X_1)}{X_1} \quad (1)$$

$$\frac{\partial \pi}{\partial P_2} = \frac{P_2}{1+r} \frac{\partial (X_2 - X_1)}{\partial P_2} + \frac{(X_2 - X_1)}{1+r} - \frac{C_2}{1+r} \frac{\partial (X_2 - X_1)}{\partial P_2} = 0$$

$$\frac{(P_2 - C_2)}{P_2} = -\frac{1}{\eta_{q2P2}} \quad (2)$$

where

$$\eta_{q1P1} = \frac{\partial X_1}{\partial P_1} \frac{P_1}{X_1} \quad , \quad \eta_{q2P2} = \frac{\partial (X_2 - X_1)}{\partial P_2} \frac{P_2}{(X_2 - X_1)} \quad , \quad \eta_{q2P1} = \frac{\partial (X_2 - X_1)}{\partial P_1} \frac{P_1}{(X_2 - X_1)}$$

$$\frac{\partial \pi}{\partial G_1} = P_1 \frac{\partial X_1}{\partial G_1} + \frac{P_2}{1+r} \frac{\partial (X_2 - X_1)}{\partial G_1} - C_1 \frac{\partial X_1}{\partial G_1} - \frac{C_2}{1+r} \frac{\partial (X_2 - X_1)}{\partial G_1} = 1 - \frac{(1-\delta)}{1+r}$$

where $\frac{\partial (X_2 - X_1)}{\partial G_1}$ consists of two terms $\frac{\partial (X_2 - X_1)}{\partial G_1} + \frac{\partial (X_2 - X_1)}{\partial G_2} \frac{\partial G_2}{\partial G_1}$

$$(P_1 - C_1) \frac{\partial X_1}{\partial G_1} + \frac{(P_2 - C_2)}{1+r} \frac{\partial (X_2 - X_1)}{\partial G_1} + \frac{(P_2 - C_2)}{1+r} \frac{\partial (X_2 - X_1)}{\partial G_2} (1-\delta) = \frac{r+\delta}{1+r}$$

$$\frac{(P_1 - C_1)}{P_1} \eta_{q1G1} + \frac{P_2}{P_1(1+r)} \frac{(P_2 - C_2)}{P_2} \frac{(X_2 - X_1)}{X_1} \left[\eta_{q2G1} + \eta_{q2G2} \frac{G_1(1-\delta)}{G_2} \right] = \frac{r+\delta}{1+r} \frac{G_1}{P_1 X_1}$$

where

$$\eta_{q2G2} = \frac{\partial (X_2 - X_1)}{\partial G_2} \frac{G_2}{(X_2 - X_1)} \quad , \quad \eta_{q2G1} = \frac{\partial (X_2 - X_1)}{\partial G_1} \frac{G_1}{(X_2 - X_1)} \quad , \quad \eta_{q1G1} = \frac{\partial X_1}{\partial G_1} \frac{G_1}{X_1}$$

substitute for price cost margins from equ 1 and 2

$$\frac{G_1}{P_1 X_1} = - \frac{P_2}{P_1(r+\delta)} \frac{\eta_{q2G2}}{\eta_{q2P2}} \frac{(X_2 - X_1)}{X_1} \frac{G_1(1-\delta)}{G_2}$$

$$- \frac{\eta_{q1G1}}{\eta_{q1P1}} \left[\frac{1+r}{r+\delta} - \frac{P_2}{P_1(r+\delta)} \frac{\eta_{q2P1}}{\eta_{q2P2}} \frac{(X_2 - X_1)}{X_1} \right] - \frac{P_2}{P_1(r+\delta)} \frac{\eta_{q2G1}}{\eta_{q2P2}} \frac{(X_2 - X_1)}{X_1} \quad (3)$$

$$\frac{\partial \pi}{\partial G_2} = \frac{(P_2 - C_2)}{1+r} \frac{\partial (X_2 - X_1)}{\partial G_2} = \frac{1}{1+r}$$

$$\frac{G_2}{P_2(X_2 - X_1)} = \frac{(P_2 - C_2)}{P_2} \eta_{q2G2}$$

substitute for price cost margin from equ 2

$$\frac{G_2}{P_2(X_2-X_1)} = -\frac{\eta_{q2G2}}{\eta_{q2P2}} \quad (4)$$

from equ 4, substitute into equ 3 and rearrange

$$\begin{aligned} \frac{G_1}{P_1X_1} \left[1 - \frac{\eta_{q2P2}}{\eta_{q2G2}} \frac{\eta_{q2G2}}{\eta_{q2P2}} \frac{(1-\delta)}{(r+\delta)} \right] = \\ -\frac{\eta_{q1G1}}{\eta_{q1P1}} \left[\frac{1+r}{r+\delta} - \frac{\eta_{q2P1}}{\eta_{q2P2}} \frac{P_2}{P_1(r+\delta)} \frac{(X_2-X_1)}{X_1} \right] - \frac{\eta_{q2G1}}{\eta_{q2P2}} \frac{P_2}{P_1(r+\delta)} \frac{(X_2-X_1)}{X_1} \end{aligned}$$

$$\begin{aligned} \frac{G_1}{P_1X_1} \left[\frac{r+2\delta-1}{r+\delta} \right] = \\ -\frac{\eta_{q1G1}}{\eta_{q1P1}} \left[\frac{1+r}{r+\delta} - \frac{\eta_{q2P1}}{\eta_{q2P2}} \frac{P_2}{P_1(r+\delta)} \frac{(X_2-X_1)}{X_1} \right] - \frac{\eta_{q2G1}}{\eta_{q2P2}} \frac{P_2}{P_1(r+\delta)} \frac{(X_2-X_1)}{X_1} \end{aligned}$$

$$\begin{aligned} \frac{G_1}{P_1X_1} = \\ -\frac{\eta_{q1G1}}{\eta_{q1P1}} \left[\frac{1+r}{r-1+2\delta} - \frac{\eta_{q2P1}}{\eta_{q2P2}} \frac{P_2}{P_1(r-1+2\delta)} \frac{(X_2-X_1)}{X_1} \right] - \frac{\eta_{q2G1}}{\eta_{q2P2}} \frac{P_2}{P_1(r-1+2\delta)} \frac{(X_2-X_1)}{X_1} \quad (5) \end{aligned}$$

APPENDIX 4.4

$$\pi_i = P_i s_{i1} X_1 - c_{i1} s_{i1} X_1 + \frac{P_2}{1+r} s_{i2} (X_2 - X_1) - \frac{c_{i2}}{1+r} s_{i2} (X_2 - X_1) - a_{i1} - \frac{a_{i2}}{1+r}$$

Expand into stock terms:-

$$\pi_i = P_1 s_{i1} X_1 - c_{i1} s_{i1} X_1 + \frac{P_2}{1+r} s_{i2} X_2 - \frac{P_2}{1+r} s_{i2} X_1 - \frac{c_{i2}}{1+r} s_{i2} X_2 + \frac{c_{i2}}{1+r} s_{i2} X_1 - a_{i1} - \frac{a_{i2}}{1+r}$$

X_1 = Total industry cumulated unit sales in period 1 (since by assumption owners purchase one unit only).

where

X_2 = Total industry cumulated unit sales in period 2.

$$X_1 = N \left[1 - F(J_1(P_1, A_1)) \right] \quad X_2 = N \left[1 - F(J_2(P_2, A_2)) \right]$$

$$X_1 = \sum_{i=1}^n x_{i1} \quad X_2 = \sum_{i=1}^n x_{i2}$$

s_{it} = An oligopolist's market share of total industry sales in period t and s_{it} is a function of the oligopolist's advertising share ie. a_{it}/A_t .

$$A_1 = \sum_{i=1}^n a_{i1} \quad A_2 = \sum_{i=1}^n a_{i2}$$

$$P_1 = f(X_1) \quad P_2 = f(X_2)$$

$$\frac{\partial \pi_i}{\partial x_{i1}} = P_1 \left[s_{i1} \frac{\partial X_1}{\partial x_{i1}} + X_1 \frac{\partial s_{i1}}{\partial x_{i1}} \right] + s_{i1} X_1 \frac{\partial P_1}{\partial x_{i1}} - c_{i1} s_{i1} \frac{\partial X_1}{\partial x_{i1}} -$$

$$c_{i1} X_1 \frac{\partial s_{i1}}{\partial x_{i1}} - \frac{P_2}{1+r} s_{i2} \frac{\partial X_1}{\partial x_{i1}} + \frac{c_{i2}}{1+r} s_{i2} \frac{\partial X_1}{\partial x_{i1}} = 0 \quad (1)$$

$$(P_1 - c_{i1}) s_{i1} \frac{\partial X_1}{\partial x_{i1}} + (P_1 - c_{i1}) X_1 \frac{\partial s_{i1}}{\partial x_{i1}} - \left[\frac{P_2 - c_{i2}}{1+r} \right] s_{i2} \frac{\partial X_1}{\partial x_{i1}} + s_{i1} X_1 \frac{\partial P_1}{\partial x_{i1}} = 0 \quad (2)$$

where

$$\frac{\partial X_1}{\partial x_{i1}} = \frac{\partial x_{i1}}{\partial x_{i1}} + \sum_{j=1}^n \frac{\partial x_{j1}}{\partial x_{i1}} \quad \frac{\partial P_1}{\partial x_{i1}} = \frac{\partial P_1}{\partial X_1} \frac{\partial X_1}{\partial x_{i1}}$$

$$\frac{\partial X_1}{\partial x_{i1}} = 1 + \lambda_1 \quad \frac{\partial P_1}{\partial x_{i1}} = \frac{\partial P_1}{\partial X_1} (1 + \lambda_1)$$

$$\frac{\partial s_{i1}}{\partial x_{i1}} = -\frac{x_{i1}}{X_1} \frac{\partial X_1}{\partial x_{i1}} + \frac{1}{X_1} \frac{\partial x_{i1}}{\partial x_{i1}}$$

$$\frac{\partial s_{i1}}{\partial x_{i1}} = \frac{1}{X_1} \left[1 - \frac{x_{i1}}{X_1} (1 + \lambda_1) \right]$$

Assuming Cournot behaviour, that is, conjectural variation $\lambda_1 = 0$ and substituting for equations into equation 2

$$(P_1 - c_{i1})s_{i1} + (P_1 - c_{i1})(1 - s_{i1}) - \left[\frac{P_2 - c_{i2}}{1 + r} \right] s_{i2} = -s_{i1} X_1 \frac{\partial P_1}{\partial X_1} \quad (3)$$

Divide through by P_1 and let $\frac{\partial P_1}{\partial X_1} \frac{X_1}{P_1} = \frac{1}{\epsilon_{X_1 P_1}}$

$$\frac{(P_1 - c_{i1})}{P_1} s_{i1} + \frac{(P_1 - c_{i1})}{P_1} (1 - s_{i1}) - \frac{(P_2 - c_{i2})}{P_2} \frac{P_2}{P_1(1 + r)} s_{i2} = -s_{i1} \frac{1}{\epsilon_{X_1 P_1}} \quad (4)$$

In order to simplify the aggregation, we shall assume that each firm faces the same cost conditions and holds the same conjectures about rival's behaviour. Thus summing over the n firms gives,

$$\frac{(P_1 - C_1)}{P_1} \sum_{i=1}^n s_{i1} + n \frac{(P_1 - C_1)}{P_1} - \frac{(P_1 - C_1)}{P_1} \sum_{i=1}^n s_{i1} - \frac{(P_2 - C_2)}{P_2} \frac{P_2}{P_1(1 + r)} \sum_{i=1}^n s_{i2} = -\frac{1}{\epsilon_{X_1 P_1}} \sum_{i=1}^n s_{i1} \quad (5)$$

and since $\sum_{i=1}^n s_{i1} = 1$ then

$$n \frac{(P_1 - C_1)}{P_1} - \frac{(P_2 - C_2)}{P_2} \frac{P_2}{P_1(1 + r)} = -\frac{1}{\epsilon_{X_1 P_1}} \quad (6)$$

or

$$\frac{(P_1 - C_1)}{P_1} - \frac{1}{n} \frac{(P_2 - C_2)}{P_2} \frac{P_2}{P_1(1+r)} = -\frac{1}{n} \frac{1}{e_{X_1 P_1}} \quad (7)$$

$$\frac{\partial \pi_i}{\partial x_{i2}} = \frac{P_2}{1+r} \left[s_{i2} \frac{\partial X_2}{\partial x_{i2}} + X_2 \frac{\partial s_{i2}}{\partial x_{i2}} \right] + \frac{s_{i2} X_2}{1+r} \frac{\partial P_2}{\partial x_{i2}} - X_1 \frac{P_2}{1+r} \frac{\partial s_{i2}}{\partial x_{i2}} - X_1 \frac{s_{i2}}{1+r} \frac{\partial P_2}{\partial x_{i2}}$$

$$-\frac{c_{i2}}{1+r} s_{i2} \frac{\partial X_2}{\partial x_{i2}} - \frac{c_{i2}}{1+r} X_2 \frac{\partial s_{i2}}{\partial x_{i2}} + \frac{c_{i2}}{1+r} X_1 \frac{\partial s_{i2}}{\partial x_{i2}} = 0 \quad (8)$$

where

$$\frac{\partial X_2}{\partial x_{i2}} = \frac{\partial x_{i2}}{\partial x_{i2}} + \sum_{j=2} \frac{\partial x_{j2}}{\partial x_{i2}}, \quad \frac{\partial P_2}{\partial x_{i2}} = \frac{\partial P_2}{\partial X_2} \frac{\partial X_2}{\partial x_{i2}}$$

$$\frac{\partial X_2}{\partial x_{i2}} = (1 + \lambda_2), \quad \frac{\partial P_2}{\partial x_{i2}} = \frac{\partial P_2}{\partial X_2} (1 + \lambda_2) \quad (8a)$$

$$\frac{\partial s_{i2}}{\partial x_{i2}} = -\frac{(x_{i2} - x_{i1})}{(X_2 - X_1)^2} (1 + \lambda_2) + \frac{1}{(X_2 - X_1)} \quad (8b)$$

Substituting for expressions 8a and 8b into equation 8 and assuming Cournot behaviour,

that is $\lambda_2 = 0$

$$\frac{\partial \pi_i}{\partial x_{i2}} = \frac{P_2}{1+r} s_{i2} + \frac{P_2}{1+r} \frac{X_1}{(X_2 - X_1)} \left[1 - \frac{(x_{i2} - x_{i1})}{(X_2 - X_1)} \right] + \frac{s_{i2} X_2}{1+r} \frac{\partial P_2}{\partial X_2} - \frac{P_2}{1+r} \frac{X_1}{(X_2 - X_1)} \left[1 - \frac{(x_{i2} - x_{i1})}{(X_2 - X_1)} \right] - \frac{s_{i2} X_1}{1+r} \frac{\partial P_2}{\partial X_2} -$$

$$\frac{c_{i2} s_{i2}}{1+r} - \frac{c_{i2}}{1+r} \frac{X_2}{(X_2 - X_1)} \left[1 - \frac{(x_{i2} - x_{i1})}{(X_2 - X_1)} \right] + \frac{c_{i2}}{1+r} \frac{X_1}{(X_2 - X_1)} \left[1 - \frac{(x_{i2} - x_{i1})}{(X_2 - X_1)} \right] = 0 \quad (9)$$

Substitute for $\frac{(x_{i2} - x_{i1})}{(X_2 - X_1)} = s_{i2}$ and rearrange

$$(P_2 - c_{i2}) s_{i2} + (P_2 - c_{i2}) \frac{X_2}{(X_2 - X_1)} (1 - s_{i2}) - (P_2 - c_{i2}) \frac{X_1}{(X_2 - X_1)} (1 - s_{i2}) + s_{i2} (X_2 - X_1) \frac{\partial P_2}{\partial X_2} = 0 \quad (10)$$

$$(P_2 - c_{i2})s_{i2} + (P_2 - c_{i2}) \frac{(1-s_{i2})}{(X_2 - X_1)} (X_2 - X_1) = -s_{i2}(X_2 - X_1) \frac{\partial P_2}{\partial X_2}$$

Multiply the RHS of equ 11 by $\frac{X_2}{X_2}$ and divide by P_2 letting $\frac{1}{\epsilon_{X_2 P_2}} = \frac{\partial P_2}{\partial X_2} \frac{X_2}{P_2}$

$$\frac{(P_2 - c_{i2})}{P_2} s_{i2} + \frac{(P_2 - c_{i2})}{P_2} (1-s_{i2}) = -s_{i2} \frac{1}{\epsilon_{X_2 P_2}} \frac{(X_2 - X_1)}{X_2} \quad (12)$$

Assuming that each firm faces the same cost conditions and holds the same conjectures about rival's behaviour, then by summing across n firms gives,

$$\frac{(P_2 - C_2)}{P_2} \sum_{i=1}^n s_{i2} + n \frac{(P_2 - C_2)}{P_2} - \frac{(P_2 - C_2)}{P_2} \sum_{i=1}^n s_{i2} = -\frac{1}{\epsilon_{X_2 P_2}} \frac{(X_2 - X_1)}{X_2} \sum_{i=1}^n s_{i2} \quad (13)$$

and since $\sum_{i=1}^n s_{i2} = 1$ then,

$$n \frac{(P_2 - C_2)}{P_2} = -\frac{1}{\epsilon_{X_2 P_2}} \frac{(X_2 - X_1)}{X_2} \quad (14)$$

or

$$\frac{(P_2 - C_2)}{P_2} = -\frac{1}{n \epsilon_{X_2 P_2}} \frac{(X_2 - X_1)}{X_2} \quad (14b)$$

$$\frac{\partial \pi_i}{\partial a_{i1}} = (P_1 - c_{i1}) \left[s_{i1} \frac{\partial X_1}{\partial a_{i1}} + X_1 \frac{\partial s_{i1}}{\partial a_{i1}} \right] - \left[\frac{P_1 - c_{i1}}{1+r} \right] s_{i1} \frac{\partial X_1}{\partial a_{i1}} = 1 \quad (15)$$

where

$$\frac{\partial X_1}{\partial a_{i1}} = \frac{\partial X_1}{\partial A_1} \frac{\partial A_1}{\partial a_{i1}} \quad (15a)$$

$$\frac{\partial A_1}{\partial a_{i1}} = \frac{\partial a_{i1}}{\partial a_{i1}} + \sum_{j \neq i} \frac{\partial a_{j1}}{\partial a_{i1}} = (1 + \mu_{i1}) \quad (15b)$$

$$\frac{\partial s_{i1}}{\partial a_{i1}} = \frac{1}{A_1}(1 - s_{i1}) - \frac{a_{i1}}{A_1^2} \mu_{i1} \quad (15c)$$

Substituting equations 15a,b,c into equation 15 and assuming zero conjectural variations, we obtain the following;

$$(P_1 - c_{i1})s_{i1} \frac{\partial X_1}{\partial A_1} + (P_1 - c_{i1}) \frac{X_1}{A_1} (1 - s_{i1}) - \left[\frac{P_2 - c_{i2}}{1+r} \right] s_{i2} \frac{\partial X_1}{\partial A_1} = 1 \quad (16)$$

Multiply through by $\frac{a_{i1}}{A_1}$ and divide through by P_1

$$\frac{(P_1 - c_{i1})}{P_1} s_{i1} \frac{\partial X_1}{\partial A_1} \frac{a_{i1}}{A_1} + \frac{(P_1 - c_{i1})}{P_1} \frac{X_1}{A_1} (1 - s_{i1}) \frac{a_{i1}}{A_1} - \frac{(P_2 - c_{i2})}{P_2} \frac{P_2}{P_1(1+r)} s_{i2} s_{i1} \frac{\partial X_1}{\partial A_1} = \frac{a_{i1}}{P_1 A_1} \quad (17)$$

Substitute for $s_{i1} = \frac{a_{i1}}{A_1}$

$$\begin{aligned} & \frac{(P_1 - c_{i1})}{P_1} s_{i1}^2 \frac{\partial X_1}{\partial A_1} + \frac{(P_1 - c_{i1})}{P_1} \frac{X_1}{A_1} s_{i1} - \frac{(P_1 - c_{i1})}{P_1} \frac{X_1}{A_1} s_{i1}^2 - \\ & \frac{(P_2 - c_{i2})}{P_2} \frac{P_2}{P_1(1+r)} s_{i2} s_{i1} \frac{\partial X_1}{\partial A_1} = \frac{s_{i1}}{P_1} \end{aligned} \quad (18)$$

Assuming that each firm faces the same cost conditions and holds the same conjectural variations about rival's behaviour, then summing across firms gives;

$$\frac{(P_1 - C_1)}{P_1} \frac{\partial X_1}{\partial A_1} \sum_{i=1}^n s_{i1}^2 + \frac{(P_1 - C_1)}{P_1} \frac{X_1}{A_1} \sum_{i=1}^n s_{i1} - \frac{(P_1 - C_1)}{P_1} \frac{X_1}{A_1} \sum_{i=1}^n s_{i1}^2$$

$$- \frac{(P_2 - C_2)}{P_2} \frac{P_2}{P_1(1+r)} \sum_{i=1}^n s_{i2} s_{i1} \frac{\partial X_1}{\partial A_1} = \frac{1}{P_1} \sum_{i=1}^n s_{i1} \quad (19)$$

Noting that $\sum_{i=1}^n s_{i1}^2$ is the Herfindahl measure of concentration H and that $\sum_{i=1}^n s_{i1} = 1$ gives;

$$\begin{aligned} & \frac{(P_1 - C_1)}{P_1} \frac{\partial X_1}{\partial A_1} H + \frac{(P_1 - C_1)}{P_1} \frac{X_1}{A_1} - \frac{(P_1 - C_1)}{P_1} \frac{X_1}{A_1} H - \\ & \frac{(P_2 - C_2)}{P_2} \frac{P_2}{P_1(1+r)} \sum_{i=1}^n s_{i2} s_{i1} \frac{\partial X_1}{\partial A_1} = \frac{1}{P_1} \end{aligned} \quad (20)$$

multiply through by $\frac{A_1}{X_1}$ letting $e_{X_1 A_1} = \frac{\partial X_1}{\partial A_1} \frac{A_1}{X_1}$

$$\begin{aligned} & \frac{(P_1 - C_1)}{P_1} e_{X_1 A_1} H + \frac{(P_1 - C_1)}{P_1} - \frac{(P_1 - C_1)}{P_1} H - \\ & - \frac{(P_2 - C_2)}{P_2} \frac{P_2}{P_1(1+r)} e_{X_1 A_1} \sum_{i=1}^n s_{i2} s_{i1} = \frac{A_1}{P_1 X_1} \end{aligned} \quad (21)$$

However since all firms are symmetric, then $H = \frac{1}{n}$ and $s_{i2} = s_{i1} = \frac{1}{n}$ thus

$$\frac{(P_1 - C_1)}{P_1} e_{X_1 A_1} \frac{1}{n} + \frac{(P_1 - C_1)}{P_1} \left[1 - \frac{1}{n} \right] - \frac{(P_2 - C_2)}{P_2} \frac{P_2}{P_1(1+r)} \frac{1}{n} e_{X_1 A_1} = \frac{A_1}{P_1 X_1} \quad (22)$$

or

$$\frac{(P_1 - C_1)}{P_1} \left[1 - \frac{1}{n} \right] + \left[\frac{(P_1 - C_1)}{P_1} - \frac{(P_2 - C_2)}{P_2} \frac{P_2}{P_1(1+r)} \right] \frac{e_{X_1 A_1}}{n} = \frac{A_1}{P_1 X_1} \quad (22b)$$

CHAPTER 5

AN EMPIRICAL INVESTIGATION OF THE ROLE OF ADVERTISING IN THE DIFFUSION OF VIDEO CASSETTE RECORDERS IN THE UK

5.1 INTRODUCTION

The purpose of this chapter is to explore empirically the two competing demand diffusion equations using data on the introduction of the video cassette recorder (VCR) in the UK. Observations for the diffusion process will be the outcome of both demand and supply side factors. In this and the following chapter, estimation will be confined to an empirical investigation of the two competing demand diffusion models only. Supply side issues will be merely relegated to a minor consideration. Indeed as stated in the opening to this thesis, many of the theoretical observations with respect to the supplier's behaviour will have to be abandoned in the empirical stage. This is obviously not an ideal situation but primarily occurs due to data limitations. Some attempt is made in the following chapter to account for the endogeneity of the advertising variable which results from recognising the supply side situation. Of course, advertising is not the only decision variable, price too may become endogenous once a monopolist or oligopolist supply structure is included. In the empirical investigation, this factor is ignored, with the supply side effectively viewed as exogenous. Interestingly, this may not be too serious a limitation in the case of video cassette recorders since there was virtually no domestic production over the majority of the period under consideration. The data series is in fact derived almost uniquely from import data.

As explained in chapter 2, initial estimation will commence with an epidemic based specification. An advertising variable will be incorporated, rationalised on the grounds of sources of information flow, rather than the innovator - imitator dichotomy of writers like Horsky and Simon (1983) (H & S) and Simon and Sebastian (1987) (S & S). The resulting equations will be observationally similar to the work of these authors, however the behavioural interpretation will be different.

It is important to begin the investigation at this point, as previous research in this field (H & S and S & S) has found a positive and statistically significant effect of advertising in the diffusion process. Yet the models employed were confined to an epidemic framework only. Unfortunately, given the absence of even moderate diagnostic testing of the chosen specification, serious misgivings must remain about the results obtained from these previous studies.

The extent of cross comparison between the following investigation and that of H & S and S & S can only be partial due to differences in the products investigated. There may be product-specific reasons why an epidemic framework is more relevant in some cases than others (for example, as argued earlier, it may be appropriate for new products which are vertically differentiated to the existing substitute good). Also the epidemic framework may appear more suitable in the presence of network externalities. The benefit derived by consumers from the use of a telephone will obviously depend upon the extent of the current (and possibly expectations of the) size of the network in existence. Consequently one of the major explanatory variables in the epidemic model, (the proportion of existing owners in the population), could be acting as a proxy for this external benefit rather than showing the effectiveness of information passed by social contact between owners and non owners.

Additionally, the effectiveness of advertising is likely to vary across products. It is commonly agreed that advertising expenditure will be more effective for consumer as opposed to producer products. Fortunately, in this latter respect, the empirical studies are consistent, as all focus upon consumer orientated goods (telephones in S & S, telephone banking services in H & S and VCR and Colour TV sets in this thesis). Of course the actual magnitude of the advertising variable's coefficient will still vary to some degree, especially since the data sets employed refer to distinct countries (W. Germany, USA, UK).

Differences also exist in the time span under consideration. In the following chapters, an attempt is made to model the diffusion process from introduction to final saturation or end of the data set, whichever occurs first. S & S begin their period of investigation when the ownership level is already 49% of the population. H & S cover the two year period from the date of introduction (no final saturation figures are given). So for all of these reasons, any cross comparisons between studies must be approximate.

5.2 ESTIMATION OF THE EPIDEMIC STRUCTURAL DEMAND DIFFUSION EQUATION

5.2.1 Estimation; The Basic Model

The basic equation to be estimated by Ordinary Least Squares (OLS) is,

$$\frac{X_t - X_{t-1}}{TVL_t - X_{t-1}} = \alpha + \frac{\beta \cdot X_{t-1} + \sum_i \chi_i \cdot Q_{it}}{TVL_t} + u_t \quad 5.1$$

where

X_t = Stock of VCRs in time t .

TVL_t = Number of TV owning/using households in time t .

α = External channel of information

β = Internal channel of information coefficient (Word of Mouth).

Q_{it} = Seasonal dummy variable in time t , $i = 3$.

u_t = Error term in time t .

(A full description of the data and variables used is given in Appendix A5 at the end of this chapter)

Equation 5.1 is simply the epidemic model written in discrete form, allowing for an additional external channel of information α . Further, the equation has been

slightly rearranged for statistical ease, by dividing through by the number of non owners in the population at time t , ie, $TVL_t - X_{t-1}$.¹

The potential population of households from which VCR owners originate is represented by the number of colour television households.² This has been done to take account of the complementary nature of the VCR machine and TV receiver. A VCR on its own is of little value and the purchase (or rental) decision is therefore conditional upon current ownership of a colour television set.³ Of course the ownership decision may be simultaneous, in that, both a colour television set and VCR are bought together, indeed combined machines are now available. By using the number of television households in time period t , rather than $t-1$, this factor will also be accounted for. Incidentally, the VCR is a good example of a product whose enjoyment from use depends to some extent upon the associated pre recorded software available (Stoneman 1989c). Whilst it would have been interesting to include the existing pre recorded video cassette catalogue, data limitations prevented the inclusion of this particular variable.

5.2.2 Advertising in the Epidemic Model; A direct Route

Initially, advertising will be incorporated by hypothesising that α is some function of advertising messages, $\alpha = f(A)$. This is analogous to the method adopted by H & S. However the exact functional form will need to be investigated. There is no *a priori* reason for expecting advertising to enter in levels or logarithms. H & S imposed a logarithmic transformation on the grounds that the effectiveness of advertising expenditure diminishes as advertising expenditures increase. Although this factor may eventually be appropriate, a similar effect is already captured. This occurs due to the recognition of time and the special features of the epidemic model. To see this,

¹. In fact, this may cause statistical problems if the error term u_t enters into the original untransformed equation. In this case, equation 5.1 will suffer from heteroscedasticity but this should be picked up by the diagnostic testing procedure.

². Where the number of colour television households is represented by the number of colour television licences in force, adjusted for evasion. See the next chapter for more detail about this variable.

³. Initially this variable was used as one of the explanatory variables on the RHS of the basic epidemic estimation equation. However this variable tended to dominate the others and increased the problems of multicollinearity. Given the complementary nature of the two products, a prior was imposed on the coefficient of the TV variable by simply taking it to the LHS of the equation.

remember that the marginal effect of advertising on sales will include the number of non owners in the potential population and this will be decreasing over time. Consequently, for a given constant response coefficient in the α function, the effectiveness of £1 spent on advertising in different time periods will decrease over time.

5.2.3 Appropriate Lag Structure

The exact lag distribution of advertising in the α function must be ascertained from the data as explained below. Once again the peculiarities of the model need to be recognised. As explained in chapter 3, a lagged effect of advertising is already inherent in the model, however this occurs indirectly via the existing ownership level variable, XT_t (where $XT_t = X_{t-1}/TVL_t$). Of course, the lagged effects of advertising could impact more directly, for the reasons already discussed (eg, durability of some forms of media such as magazines, the information from which can be transmitted to potential owners in following periods).

The appropriate number of lags to include in empirical models has always proved problematic. Normally there is very little theoretical guidance in the area and so the decision is left to the data. An econometric approach which has gained in popularity (eg. Sargan 1964 and Hendry and Mizon 1978), recommends the estimation of a general model in which the dynamics are of a relatively high order and then move towards a more specific formulation by searching for common factors in the lag structure. However this approach should not be adopted uncritically. The possible problems from multicollinearity and loss of degrees of freedom will remain. Also, the exact lags left as a consequence of following this method may be difficult to justify on economic grounds (for example say lags 3 and 5 only remain, then such lags would be difficult to rationalise).

In addition, in this particular case, the dynamics of the model have been partially indicated at the outset due to the adoption of the epidemic model. Consequently the focus of attention will rest upon the advertising variable, which *a priori*, is expected

to have an additional direct lagged impact in the model due to the creation of a stock of goodwill as already discussed in Chapter 3. Data limitations restrict the number of observations to a maximum of 40. Therefore practical considerations will necessarily confine the order of the lags that can be included directly in the specifications.

Previously, researchers have circumvented this problem to some extent by using extraneous information about the specification of the lag structure. Lagged effects arise for many reasons. How the total lagged effect is distributed over time is an area devoid of much theoretical foundation. An infinite geometrically declining lag structure (such as that proposed in equation 5.1.4 below) can exploit the Koyck transformation process in the estimation stage. The theoretical justification for such a structure tends to be rather *ad hoc*. Many applications using such a lag distribution appeal to the theory of adaptive expectations. The expectation variable becomes a weighted average of the existing variable and past values using geometrically declining weights. Alternatively, the resulting lag structure has been justified on the grounds that economic agents do not adjust instantaneously to new market situations (possibly because of costs of adjustment).

Unfortunately, this particular lag distribution imposes a continual decline in the coefficient of the lagged explanatory variable. Any alternative structure, such as a peak effect in the lag distribution is therefore ruled out by assumption. There may be *a priori* reasons for expecting that the major impact is delayed for some periods. Almon (1965) incorporated a peak effect in the lag distribution in her empirical investigation of investment expenditures. There are specific technical and subjective factors which apply particularly to capital investment decisions. For example, there may be a decision making delay whilst firms ascertain whether the increase in output (which prompted the investment decision) is temporary or permanent. In addition, there may be administration delays in raising the finance for the expenditure. Furthermore, if the capital good is of a particular specification, it is unlikely to be available for immediate delivery. Consequently the delay will depend upon the amount of spare capacity in the capital goods sector. For all these reasons, using a lag structure which assumes the maximum

impact in the current period (such as the Koyck model) may be theoretically inappropriate. A polynomial lag structure which allows for several periods delay before the major impact is felt (such as that given in equation 5.1.3 below) is more likely to prove satisfactory. However the Almon method whilst having the advantage of allowing for a peak effect, is not without its own disadvantages. Since the lag distribution is finite, the number of lags to include must be chosen arbitrarily at the outset, as must the degree of the polynomial. This will be discussed in more detail later in the chapter.

In this particular empirical investigation, the variable which is expected to have a lagged effect is advertising expenditures (as previously explained) and the theoretical justification for any specific lag structure is open to debate. Say the reason for the lag is due to the existence of advertising in a durable form, then it would seem reasonable to assume a geometrically declining lag structure since the media eventually becomes out of date and obsolete. On the other hand, if the model was explaining replacement sales in addition to the initial acquisition of the new product, then a peak effect may be appropriate since it could be picking up the brand loyalty (habit) effect when the consumer re-enters the market.

Additionally, some of the reasons advanced for a peak effect with respect to capital goods investment, would not seem altogether suitable in this particular investigation. For example, it would appear naive for firms to advertise against a background of supply constraints. This would also appear likely even if there was a separation between the advertiser and manufacturer of the product (eg. if the firms undertaking the advertising belong to the retail sector). In any case, it is much more likely that in comparison to specific capital equipment, stocks of finished durable goods would be held, thus reducing the possibilities of delay in obtaining the good.

On balance, there does not appear to be any clear *a priori* preference for a particular lag distribution. Consequently, it will be left to the data to discriminate. Therefore, the following advertising specifications in the α function will be investigated;

$$1) \quad \alpha = g + \sum_i a_i \cdot A_{t-i} \quad 5.1.1$$

where $i = 0$ in model 5.1.1 and $i = 4$ in model 5.1.1B as quarterly data is being used.

$$2) \quad \alpha = g + \sum_i a_i \cdot \ln A_{t-i} \quad 5.1.2$$

$$3) \quad \alpha = g + a_i \cdot A_{t-i} \quad 5.1.3$$

$$a_i = \delta^i \cdot a, \quad i = 0, 1, \dots, \quad 0 < \delta < 1 \quad (\text{Koyck})$$

$$4) \quad \alpha = g + a_i \cdot A_{t-i} \quad 5.1.4$$

$$a_i = l_0 + l_1 \cdot i + l_2 \cdot i^2 + \dots + l_r \cdot i^r \quad (\text{Almon})$$

r = degree of polynomial, $i = 1, \dots, s$, lag length

Allowing the parameter a_i to be a quadratic function, as in equation 5.1.4, means that it can take many shapes. The imposition of end point zero restrictions could be used to ensure a more plausible shape to the lag distribution. However such restrictions can lead to biased estimates of the remaining non zero parameters. Consequently, if a particular end point is to be zero, it may be better to simply reduce the maximum lag length rather than impose a restriction.

5.2.4 Estimation Results

5.2.4.1 The Basic Model

To start with, the simple epidemic model without advertising, (equation 5.1) was estimated by OLS. The results are given in Table 5.A. The explanatory variables have the expected effect. There is a positive and statistically significant social contact coefficient β and the seasonal dummies for quarters 1 to 3 are negative suggesting that sales in this period are significantly below the 4th quarter. The seasonality of the data showing higher sales in quarter 4 is clearly evident in diagram A5.2 in the appendix to this chapter.

However the diagnostic tests indicate problems which is not surprising given that many of the classical assumptions underlying the linear regression model are violated. For example, the disturbance terms u_t appear to be serially correlated (autocorrelation) and have a non constant variance (heteroscedasticity). The breakdown in the assumption of a constant variance is most likely to occur when there is a large variation in the size of the explanatory variables. This is more normally the case when cross sectional data is being used (for example, the variance of consumption is likely to be greater for higher income families than for lower income ones).

However such a range of variation in the explanatory variables need not be restricted to cross sectional observations. Also, if the time span considered in time series data is long, then a problem of heteroscedasticity may be encountered. It could be the case that over time the data collection technique improves. Thus errors from this source may decline in importance, leading to a non constant variance of the disturbance term. Furthermore, the heteroscedasticity test may be indicative of a mis-specified model. An omitted trending variable will have the effect of producing a non constant variance, as will an explanatory variable's coefficient which is subject to change over time. Another potential source of heteroscedasticity in time series data would be the inappropriate transformation of the variables. Many of these issues will be referred to again in the following empirical results as appropriate.

TABLE 5.A

OLS Estimation of the Epidemic Model.
 Dependent variable, TDP = $(X_t - X_{t-1})/TVL_t - X_{t-1}$

	MODEL 5.1	MODEL 5.1.1	MODEL 5.1.1B
CONS	0.0258 (0.5316e-02) **	-0.1013e-02 (0.6975e-02)	-0.2234e-03 (0.9432e-02)
XT _t	0.1012 (0.0109) **	0.0932 (0.8651e-02) **	0.0922 (0.0103) **
Q _{1t}	-0.0258 (0.6607e-02) **	-0.6163e-02 (0.6590e-02)	-0.5951e-02 (0.0113)
Q _{2t}	-0.0288 (0.6435e-02) **	-0.0132 (0.5988e-02) *	-0.0134 (0.9130e-02)
Q _{3t}	-0.0217 (0.6430e-02) **	-0.5566e-03 (0.6697e-02)	-0.5139e-03 (0.0114)
λ _t		0.9500e-05 (0.2000e-05) **	0.9200e-05 (0.2500e-05) **
λ _{t-1}			-0.1000e-06 (0.2800e-05)
λ _{t-2}			-0.9000e-06 (0.2700e-05)
λ _{t-3}			-0.5000e-06 (0.2800e-05)
λ _{t-4}			0.1300e-05 (0.2900e-05)
NOB	39	39	36
RSS	0.7025e-02	0.4153e-02	0.3807e-02
DW	1.0801	1.6061	1.5389
AR ²	0.7454	0.8449	0.8166
LM4	Reject	Accept	Accept
RSET	Reject	Reject	Reject
NORM	Accept	Accept	Accept
HET	Reject	Reject	Accept

Standard errors in parentheses.

*, ** denotes significance at 5% and 1% respectively.

It is important to bear in mind that a whole host of diagnostic tests are being applied to the estimated model. Care must be taken not to view narrowly any one particular test statistic as indicative of one particular type of specification error. In fact, a combination of the results from several test statistics can be more informative. In addition to the overall information obtained from the statistical diagnostic tests, any particular model must be judged in relation to the economic plausibility of the results. For example, if the diagnostic tests indicate a robust model yet the sign of the coefficient of an economic variable is opposite to that expected, this would indicate some suspicions regarding the model's structure and warrant further investigation.

It is in this sense that the diagnostic test results are interpreted, unless there is *a priori* information which may hint at a particular problem. For example, in deriving the basic epidemic estimation equation 5.1, the original theoretical equation 3.1 was transformed by dividing through by the remaining population of non owners in each period ie. $TVL_t - X_{t-1}$. Also, as explained in the next chapter, advertising data for later periods in the colour tv model may reflect true expenditures more accurately than for earlier years, thus opening up the possibility for a non constant variance of the disturbance term.

There are a number of heteroscedasticity tests which could be applied. The implicit assumption underlying them is that the variance of the disturbance term is related to some unknown variable(s). The tests differ in their use of different proxies or surrogates for this unknown relationship. The tests further differ in respect of whether the functional specification itself is explicitly expressed (eg. the Glejser test) or not (eg. the White test). The main test of heteroscedasticity quoted throughout the empirical investigation following in Chapters 5 and 6 employs the square of the fitted values from the regression equation as a surrogate for the unknown variable to which the disturbance term is assumed to relate.

The Reset test proposed by Ramsey (1969) can be used as a test for specification error due to omitted variables. Suppose that the true relationship is $y_t = a + b_1.X_{1t} + b_2.X_{2t} + e_t$, where X_{2t} is unobservable such that the false equation $y_t = a + b_1.X_{1t} + v_t$ is estimated instead. The disturbance term v_t will include the influence of the omitted variable. The Reset test examines the relationship of X_{2t} to the false equation's error term v_t . Since the omitted variable is unobservable, a proxy variable must be used instead (the Reset test employed in these chapters takes the square of the fitted values obtained from the false regression equation). As higher powers of the fitted values can also be used as the proxy, this test is also appropriate for picking up suspected functional mis-specification.

The rejection of the Ramsey Reset test in model 5.1 casts some doubt on the chosen functional form. However given the failure of the other diagnostic tests as already discussed, it seems likely that the tests are indicating that the simple epidemic model 5.1 is mis-specified and consequently, does not appear to be an adequate representation of the diffusion of the VCR in the UK.

5.2.4.4 Advertising; A Direct Route

The failure of the simple model should not be surprising, given the omission of the hypothesised role for advertising in the epidemic framework. So the next step is to include advertising in the model and the results are again shown in Table 5.A. Compared to the simple epidemic model, inclusion of current advertising messages (model 5.1.1) appears to lead to some improvement. For example the adjusted R^2 increases from 0.7454 to 0.8449. Of course this statistic by itself is not very informative, as high values can easily be obtained in time series regression and may be biased if the classical assumptions of the linear regression model are violated. It is interesting to note that autocorrelation no longer appears to be a problem. The DW statistic now falls just inside the top end of the inconclusive region. Of course given the use of quarterly data, a test for higher order autocorrelation is more appropriate. Confidence in the null hypothesis of no serial correlation is confirmed by the acceptance of the Lagrange Multiplier (LM) test

statistic suggested by Godfrey (1978) under the null hypothesis of no autocorrelation, both for order 1 and up to order 4. Thus the residual e_t from the original regression equation is regressed on the original explanatory variables and the first lag of the residual e_{t-1} . For autocorrelation up to order 4, the test is repeated using the first four quarter lags of the residual e_{t-1} , e_{t-2} , e_{t-3} and e_{t-4} as the additional explanatory variables in the second stage regression.

The explanatory variables have the expected sign, with advertising messages exerting a statistically significant positive influence. Unfortunately, the heteroscedasticity test is rejected and consequently the estimated standard errors will be biased. As explained above, there are *a priori* reasons for expecting this, due to the transformation of the original diffusion equation. Therefore a simple Glejser test was undertaken with the absolute error from equation 5.1.1 regressed on the suspected variable ie. the number of non owners ($TVL_t - X_{t-1}$). The estimated coefficient on this variable was statistically significant at the 5% level only. Given that the specification of model 5.1.1 remains suspicious (as the Reset test is also rejected), the failure of the heteroscedasticity test could be further evidence of mis-specification rather than an indication of a specific problem.

A useful complement to the more formalised diagnostic tests, is a visual inspection of the residuals from the estimation. A plot of the actual and fitted values shows the estimated model producing values up to mid 1982 with far more seasonal variation than was evident in the actual series. Of course, the seasonal variation in the actual series for 1978 and 1979 was estimated and the actual quarterly observations interpolated using this information. It is quite feasible that this correction factor underestimated the true seasonal variation during these early years. However, this still leaves unexplained why the difference between the actual and fitted values in 1980 to mid 1982 remained, given that these quarterly observations were obtained directly from source. An inspection of the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) of the recursive residuals gives further evidence of a mis-specified model.

As a result the model was not simply transformed to remove the heteroscedasticity and re-estimated. Instead an alternative model using a logarithmic transformation of the advertising variable was investigated (5.1.2). The deterioration in all of the diagnostic tests performed indicates this particular step to be non beneficial and therefore the results are not reported.

5.2.4.3 Extending The Dynamics; Stock of Goodwill

Another possibility worth investigating is the dynamics of the advertising variable. So far only current advertising has been included in the model. However, as argued earlier, there are *a priori* reasons for expecting lagged values of this variable to enter directly into the model. Consequently models 5.1.1B, 5.1.3 and 5.1.4 were estimated. The number of lags included in 5.1.1B was limited on practical grounds due to loss of degrees of freedom when using a relatively small sample size of 40 observations. Also it is quite likely that lagged values especially in the corresponding quarter of previous years will be highly correlated, leading to problems of multicollinearity.⁴

There is also some evidence from the literature that the lasting effects of advertising are short lived (eg. Clarke 1979), although care must be taken when extrapolating from these studies as most refer to existing and mainly non durable products and it is quite likely that the depreciation rate of advertising will be product specific. The simple fact that purchases of durable products are undertaken relatively infrequently is one reason why the lasting effect of advertising may be longer for such goods.

Mainly for practical reasons, the number of lags included in model 5.1.1, given that quarterly data is being used, is restricted to 4. So the total effect of advertising would be complete in 15 months. The results for this particular specification are labelled model 5.1.1B in Table 5.A. Whilst the coefficient on the current advertising variable remains positive and significant, the individual lagged variables are insignificant and some have

⁴. For example the correlation coefficient between A_t and A_{t-4} was 0.67.

an unexpected negative signed coefficient (although not statistically significant). A joint test restricting the lagged advertising variables to be zero is accepted. Unfortunately, the failure of the Ramsey Reset test indicates that there are still problems with the model.

Of course, the arbitrary restriction to only 4 lags may be criticised. Thus an infinite geometrically declining lag structure was hypothesised and a Koyck transformation applied to the basic equation. These results are labelled model 5.1.3 and reported in Table 5.B. The coefficient on the current advertising variable remains positive and statistically significant. The coefficient on the lagged dependent variable represents one minus the rate of decay of the advertising variable. Its value of 0.27 implies a fairly rapid rate of decay in the lag distribution, giving some *ex post* justification for using a limited number of lags directly in equation 5.1.1B. Unfortunately this coefficient is not statistically significant. Also the existing ownership variable XT_t , no longer has the expected positive influence, although the coefficient is not statistically significant. The poor performance of the lagged dependent variable and the existing ownership variable may be due to multicollinearity since there is strong correlation between each of these explanatory variables.⁵

The Koyck transformation does possess certain estimating advantages, by reducing the number of parameters to be estimated. However the transformation process itself might be expected to induce serial correlation into the error term. If so, OLS estimated parameters will be biased and inconsistent. Surprisingly, the LM test up to order 1 and 4 seem to accept the null hypothesis of no autocorrelation.

Of course the imposition of a continually declining lag structure, may not be appropriate. Therefore further investigations were conducted using an Almon polynomial lag distribution, which allows for the possibility of a peak effect. The order of the polynomial must be specified in advance and this was arbitrarily set to 3. The number of finite lags to include must also be specified at the outset. Given the indications from the

⁵. For example, the correlation coefficient between XT_t and XT_{t-1} is 0.998, and between TDP_t and XT_t is 0.782.

TABLE 5.B

OLS Estimation of the Epidemic Model.
Dependent variable, $TDP = (X_t - X_{t-1})/TVL_t - X_{t-1}$

MODEL 5.1.3		MODEL 5.1.5	MODEL 5.1.4 ⁺	
CONS	-0.7694e-03 (0.7579e-02)	-0.1989e-02 (0.7961e-02)	CONS	0.4839e-02 (0.8165e-02)
XT _t	-0.1336 (0.4161)	0.0923 (0.9333e-02) **	XT _t	0.1035 (0.0104) **
Q _{1t}	-0.8678e-02 (0.8909e-02)	-0.5352e-02 (0.7307e-02)	Q _{1t}	-0.0163 (0.7257e-02) *
Q _{2t}	-0.0139 (0.6424e-02) *	-0.0123 (0.6810e-02) *	Q _{2t}	-0.0118 (0.8746e-02)
Q _{3t}	0.3501e-03 (0.7281e-02)	0.3085e-03 (0.7487e-02)	Q _{3t}	-0.8872e-02 (0.8299e-02)
A _t	0.9300e-05 (0.2400e-05) **	0.1000e-04 (0.2700e-05) **	W0 _t	0.8200e-05 (0.2400e-05) **
ACD _t		-0.7000e-06 (0.2500e-05)	W1 _t	-0.7500e-05 (0.4400e-05)
XT _{t-1}	0.2105 (0.4062)		W2 _t	0.2500e-05 (0.1900e-05)
TDP _{t-1}	0.2707 (0.3029)		W3 _t	-0.3000e-06 (0.2000e-06)
NOB	38	39	NOB	34
RSS	0.3885e-02	0.4143e-02	RSS	0.3190e-02
DW	N/A	1.5942	DW	2.1107
AR ²	0.8397	0.8405	AR ²	0.8366
LM4	Accept	Accept	LM4	Accept
RSET	Reject	Reject	RSET	Reject
NORM	Accept	Accept	NORM	Accept
HET	Accept	Reject	HET	Accept

Standard errors in parentheses.

*, ** denotes significance at 5% and 1% respectively.

+ Polynomial of degree 3 and 6 quarters lag.

estimations already undertaken, a relatively short maximum period of 8 quarters was chosen. Estimation was repeated, gradually reducing the maximum number of lags to 4. The Almon method, using a third order polynomial requires the estimation of 4 parameters with respect to the advertising variables, regardless of the number of lags chosen. Therefore to go below 4 would be superfluous, simply including the lags directly (as in model 5.1.1B) is more efficient.

Throughout these estimations, the failure of the Reset test remained, but ignoring this diagnostic for the moment, on balance a lag length of 6 seemed most appropriate. The implied values for the coefficients on the advertising variables can be deduced from the estimated parameters on the composite variables W_0, \dots, W_3 and the following relationship,

$$a_i = l_0 + l_1.i + l_2.i^2 + l_3.i^3 \quad \text{and } i = 6$$

Unfortunately, some of the derived coefficients on the lagged advertising variables were negative, which does not make economic sense. This, in addition to the failure of the Reset test, continues to cast doubt on the suitability of this particular structure.

5.2.4.4 Advertising and Inter Brand Rivalry

The epidemic model with the inclusion of a current advertising variable does produce some interesting results, although the consistent failure of the Reset test statistic may be indication that the direct route for advertising may not be appropriate. However before turning to the alternative route by which advertising can enter into the epidemic framework, there is one further refinement to the advertising variable which should be tested. As explained in chapter 3, the advertising variable represents the total number of real advertising messages transmitted by all firms in the market. The re-distribution effects of advertising amongst rival firms is effectively being ignored, so that attention can focus on the total market effect of advertising. Because the inter brand rivalries are

being ignored, the estimation of the total market marginal advertising response coefficient proceeds on the implicit assumption of no changes in the underlying competitive structure or behaviour of firms.

A closer inspection of the raw advertising data reveals that in addition to an increase in the average volume of advertising in 1982, there is a considerable increase in the number of identifiable brands advertised during this period. In fact the period 1981, 82 and 83 shows the greatest turbulence in terms of previously un-advertised brands appearing, however 1982 is worst affected. This might be explained by the relaxation (or expectation of the relaxation of) hire purchase controls in the latter half of this year. In addition, the attempt to lock new consumers into a particular industry standard could have intensified the amount of rivalrous advertising undertaken during this period. This sudden appearance of a relatively large number of previously un-advertised brands, may result in the true marginal effectiveness of total advertising on the total market during this period being below that estimated from the entire sample period. In order to allow for this factor, a multiplicative dummy was formed so that,

$$\alpha = a_0 + (a_1 + a_2.D_t).A_t$$

where

$$D = \begin{cases} 1 & \text{when } t = 1982 \\ 0 & \text{otherwise} \end{cases}$$

$$\text{and } a_1 > 0, \quad a_2 < 0$$

The results are labelled model 5.1.5 in Table 5.B. As usual, XT_t has a positive and significant coefficient, as does current advertising A_t . The multiplicative dummy variable has the expected negative sign but since the coefficient a_2 , is not statistically significant, no conclusions should be drawn. A joint test of significance of a_1 and a_2 being greater than zero was accepted. However doubts about the model's specification

must remain given the consistent failure of the Reset test coupled with the rejection of the heteroscedasticity test.

5.2.5 Advertising in the Epidemic Model; An Indirect Route

As already explained, the Reset test can be an indication of general misspecification or in particular, show that the chosen functional form of the model is inappropriate. Discussion in chapter 2 suggested that advertising could enter into the epidemic model through the social contact coefficient β in equation 5.1, thus altering the functional form of the model. S & S explicitly model this hypothesis. Their data set covers the later stages of the diffusion process and they argue that the direct effect of advertising may be more relevant in the early stages. The alternative estimating equation when advertising enters via the word of mouth coefficient is as follows,

$$\frac{X_t - X_{t-1}}{TVL_t - X_{t-1}} = a + \frac{\beta \cdot X_{t-1} + \sum_{i=1}^n \chi_i \cdot Q_i}{TVL_t} + u_t$$

where

$$\beta = f(A) \quad 5.2$$

5.2.5.1 Estimation Results; Advertising An Indirect Route

The results of estimating 5.2 are given in Table 5.C. When β is dependent on current advertising ie. $\beta = b_1 + b_2 \cdot A_t$ (model 5.2.1), the variables have the expected positive signs and the estimated coefficients are statistically significant (although given the failure of the Lagrange Multiplier test for autocorrelation up to order 4, this statement should be treated with caution). Whilst the Reset test is now accepted, (suggesting that this change in functional specification may be preferable to advertising entering directly via the α function) the presence of autocorrelation is now indicated. So further

TABLE 5.C

OLS Estimation of the Epidemic Model.
 Dependent variable, $TDP = (X_t - X_{t-1})/TVL_t - X_{t-1}$

	MODEL 5.2.1	MODEL 5.2.2
CONS	0.0135 (0.4713e-02) **	0.0175 (0.5768e-02) **
XT_t	0.0631 (0.0112) **	0.0571 (0.0238) *
Q_{1t}	-0.9949e-02 (0.5918e-02)	-0.0120 (0.8011e-02)
Q_{2t}	-0.0143 (0.5672e-02) **	-0.0159 (0.7182e-02) *
Q_{3t}	-0.4637e-02 (0.5945e-02)	-0.0113 (0.8017e-02)
AXT_t	0.2300e-04 (0.4500e-05) **	0.2400e-04 (0.7600e-05) **
AXT_{1t}		-0.3200e-05 (0.7500e-05)
AXT_{2t}		-0.1200e-05 (0.7400e-05)
AXT_{3t}		0.8400e-05 (0.6900e-05)
AXT_{4t}		-0.3400e-05 (0.9300e-05)
NOB	39	36
RSS	0.3949e-02	0.3423e-02
DW	1.2783	1.2836
AR^2	0.8525	0.8351
LM4	Reject	Reject
RSET	Accept	Accept
NORM	Accept	Accept
HET	Accept	Accept

Standard errors in parentheses.

*, ** denotes significance at 5% and 1% respectively.

experimentation with the lag structure of the advertising variable in the β function was undertaken.

5.2.5.2 Extending the Dynamics

To begin with, additional lagged advertising variables are included directly into the β function. Again for practical reasons, a maximum of 4 lags are used. The results are labelled model 5.2.2 in Table 5.C. Unfortunately, a LM test for autocorrelation up to order 1 and 4 still rejects the null hypothesis of no serial correlation. Thus the statistical significance of the variable coefficients must be treated with caution since the estimated variance of the parameters will be inefficient in the presence of autocorrelation. Bearing this in mind, the existing ownership variable XT_t remains positive but the coefficient is only significant at the 5% level. The size of the advertising variables coefficient is very close to that estimated in the previous model (5.2.1) but is now significant.

None of the additional lagged variables are statistically significant and some have an unexpected negatively signed coefficient. Experimentation with joint tests of zero restrictions on the coefficients, suggests that, adding lagged advertising variables to the β function, does not improve matters overall. Further investigation of the lag structure within this particular specification was not considered worthwhile. An infinite geometrically declining lag structure could not be easily estimated as the Koyck transformation process does not reduce the number of parameters. This occurs due to the presence of the multiplicative term, as the transformed equation becomes,

$$\begin{aligned} TDP_t - TDP_{t-1} = & \alpha(1-\delta) + b_0XT_t - \delta b_0XT_{t-1} \\ & + a_1A_tXT_t + \delta a_1A_{t-1}(XT_t - XT_{t-1}) \\ & + \delta^2 a_1A_{t-2}(XT_t - XT_{t-1}) \dots \end{aligned}$$

Whilst an assumption that $(XT_t - XT_{t-1})$ tends to zero would solve the problem this is clearly not feasible. An Almon lag distribution is more amenable, however given the previous results, it is unlikely that such a transformation will be

rewarding. Instead, attention is directed towards the possible effects of a changing competitive situation on the advertising response coefficient.

5.2.5.3 Advertising, Interbrand Rivalry and Hire Purchase Restrictions

A multiplicative dummy variable, where D_t is as described previously, was added to equation 5.2, so that,

$$\beta = b_1 + (b_2 + b_3 D_t) \cdot A_t$$

The resulting estimates are shown in Table 5.D. Again XT_t has a positive and statistically significant coefficient, as does current advertising. However, now the multiplicative dummy variable does not have the expected negative influence, which is necessary to reduce the magnitude of the overall advertising coefficient if the hypothesis is correct. Instead b_3 is positive and statistically significant. Interestingly, the diagnostic tests are all accepted. It may be that the multiplicative dummy variable is in fact picking up a product variety effect. If the number of previously un-advertised brands actually represents the number of new brands becoming available, this increase in product variety could be having a positive effect on ownership. Alternatively, the multiplicative dummy variable may be indirectly capturing the effect of hire purchase restrictions. It is likely that the removal of these restrictions, which occurred in 1982q3, will have a positive effect on the dependent variable. When the HP variable is omitted from the equation, but a multiplicative dummy for the period 1982 is included, this positive effect may show up through the advertising coefficient and swamp the expected negative competitive influence.

Further investigation of the specification was undertaken to test for structural change and the predictive power of the model. Both of these statistics are credited to Chow. In testing for structural change, a standard F test is being used to test whether the parameters of one data set (period 1) are significantly different from the parameters of a second data set (period 2). Using 1982q3 as the break point (the date when hire purchase

TABLE 5.D

OLS Estimation of the Epidemic Model.
Dependent variable, TDP = $(X_t - X_{t-1})/TVL_t - X_{t-1}$

	MODEL 5.2.3	MODEL 5.2.4	MODEL 5.2.5
CONS	0.0111 (0.4379e-02) **	0.0128 (0.4782e-02) **	0.8748e-02 (0.4448e-02) *
XT_t	0.0679 (0.0103) **	0.0660 (0.0116) **	0.0673 (0.0100) **
Q_{1t}	-0.8878e-02 (0.5408e-02)	-0.0100 (0.5923e-02)	-0.6538e-02 (0.5362e-02)
Q_{2t}	-0.0146 (0.5171e-02) **	-0.0152 (0.5756e-02) **	-0.0119 (0.5088e-02) *
Q_{3t}	-0.3635e-02 (0.5430e-02)	-0.4626e-02 (0.5949e-02)	-0.1669e-02 (0.5358e-02)
AXT_t	0.2200e-04 (0.4200e-05) **	0.2250e-04 (0.4600e-05) **	0.4640e-04 (0.8500e-05) **
COMP_t	0.3440e-04 (0.1240e-04) **		
HP_t		0.1940e-04 (0.1990e-04)	
HPT_t			0.2330e-04 (0.7400e-05) **
NOB	39	39	39
RSS	0.3181e-02	0.3835e-02	0.3015e-02
DW	1.6453	1.3921	1.7618
AR²	0.8775	0.8523	0.8839
LM4	Accept	Reject	Accept
RSET	Accept	Accept	Accept
NORM	Accept	Accept	Accept
HET	Accept	Accept	Accept

Standard errors in parentheses.

*, ** denotes significance at 5% and 1% respectively.

restrictions were removed) the Chow test indicates no structural change in the parameters. However Chow's second test, which is a modification to the original test statistic for the situation when too few observations exist in the second period to enable a second regression to be performed, can also be used as a test of prediction failure of the model. This statistic was rejected for the model given in Table 5.D. This poor prediction performance after 1982q3, coupled with the unexpected positive coefficient on the multiplicative dummy variable may cast doubt on this particular specification, when applied to the full sample period.

Given one of the *ex post* justifications for the positive b_3 coefficient, a dummy variable representing the relaxation of HP restrictions was substituted for the competitive dummy variable D_t . The minimum deposit required over this period only took two values, 20% before 1982q3 and zero thereafter. A dummy was constructed taking a value of 1 up to and including 1982q2 and zero for the remaining observations. The expected sign of the coefficient on the multiplicative dummy term is negative. Unfortunately as can be seen from the results labelled model 5.2.4 in Table 5.D, the estimated coefficient has a positive sign, although insignificant. Additionally, the model specification looks suspicious due to the failure of the LM test for autocorrelation up to order 4. A plot of the CUSUM of the recursive residuals gave further strong evidence of the lack of robustness of this model.

The effect of relaxing credit restrictions may only bring purchases of VCRs by new owners forward in time.⁶ In fact the poor predictive performance of model 5.2.3 (which picked up a one off positive effect on the advertising response coefficient in 1982) was demonstrated by a systematic over prediction of the dependent variable after this period. Consequently, an alternative dummy variable was established such that,

$$D = \begin{cases} 0 & 1978q1 \text{ to } 1982q2 \end{cases}$$

⁶ Cuthbertson 1980 in his investigation of expenditure on consumer durable also argued that the HP variable is more likely to have a transitory effect on the level of durable expenditure.

$$= 1 \quad 1982q3 \text{ and } q4$$

$$= -1 \quad 1983q1 \text{ to } 1987q4$$

In this case, a positive coefficient would be expected on the multiplicative dummy variable. The results are labelled 5.2.5 in Table 5.D. All the variables produce the expected positive coefficients which are statistically significant. The diagnostic tests are all accepted, although the test for normality falls very close to the boundary between the acceptance and rejection region. LM tests for autocorrelation up to order 1 and 4 fall well within the acceptance zone. A visual inspection of the residuals and recursive residuals also indicate a better specified model.

The estimated parameters show that the effectiveness of communication by social contact on the number of new owners to non owners is 0.0673 when no advertising is undertaken. During a period of credit restrictions, this effectiveness increases slightly to 0.06735 as a result of advertising messages. When the restrictions are removed, the marginal impact of advertising is increased so that β is now 0.06737. However this additional positive effect is merely a shift forward in time such that, 6 months after the removal of the restrictions, the indirect marginal advertising response coefficient reduces to $0.231e-04$ so the social contact coefficient after 1982 is 0.06732. A further exploration of this model shows that whilst a Chow test indicates no structural break after 1982q3, the predictive ability of the model, although improved relative to previous models, still rejects the null hypothesis that the predictions errors are insignificant.

5.2.6 Preliminary Conclusions

The results obtained in this final model (5.2.5) are certainly interesting. On balance, taking account of both the statistical diagnostic tests and the economic plausibility of the results, the alternative specification with current advertising entering indirectly through the social contact coefficient seemed preferable. It is quite possible that producers' information needs to be confirmed by the experience of the new product by an existing owner, especially for a product such as the VCR which was a completely

new good in the sense that no substitute product existed. Whilst the magnitude and significance of the coefficients on the explanatory variables were fairly robust within a particular epidemic structure, the magnitude of the β coefficient was particularly sensitive to the specification hypothesised for the advertising information channel in the epidemic model. Consequently, this emphasises that the extent of econometric testing is important if reliable estimates of the parameters of the epidemic model are to be obtained.

The final model estimated (5.2.5), with the indirect marginal effectiveness of advertising increasing when HP controls were removed but reducing thereafter, did appear to provide an empirically robust model. However it was disappointing that the predictive ability of this model was suspect. Of course, the economic foundations of the underlying epidemic framework is limited and it is quite possible that other important economic variables have been omitted. Some further attempt could have been made to incorporate additional economic variables in an *ad hoc* manner. However, the alternative probit model proposed in chapter 4 which has a richer microeconomic base will be investigated to see whether more satisfying econometric results emerge. It is to this stage that the investigation now proceeds.

5.3 ESTIMATION OF THE PROBIT STRUCTURAL DEMAND DIFFUSION EQUATION

5.3.1 Estimation; The Static Equilibrium Model

One of the major shortcomings of the epidemic model is the failure to allow for the heterogeneity of the population from which the new owners of the product originate. The probit based model, having as its foundation the recognition of such differences, enables further economic variables to be incorporated in a more satisfying manner than simply adding them to the epidemic structure in an *ad hoc* and logically inconsistent manner. The alternative theoretical model presented in chapter 4 (and developed to include advertising) results in the following simple structural demand diffusion equation:-

$$\log (X_t / (N_t - X_t)) = - (Z_t^*)$$

and $Z_t^* = f(A_t, P_t, R_t)$

so the estimating equation assuming Z_t^* is a linear function of the economic variables is as follows,

$$Y_t = \chi_0 + \chi_1 \cdot A_t + \chi_2 \cdot P_t + \chi_3 \cdot R_t + \sum_i \chi_i \cdot Q_{it} + u_t$$

$$\chi_1 > 0 \quad \chi_2 < 0 \quad \chi_3 < 0 \quad \chi_i < 0 \quad 5.3$$

where

X_t = Stock of VCR in time t

A_t = Total number of advertising messages in time t

P_t = Relative retail price of VCR in time t

R_t = Real rate of interest in time t

N_t = Number of households in the population.

$$Y_t = \log (X_t / (TVL_t - X_t))$$

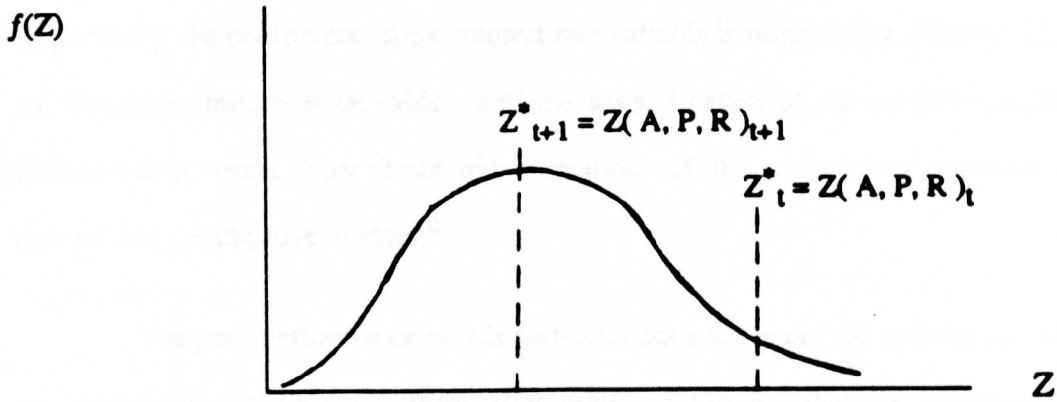
TVL_t = the number of colour tv owning/using households in the UK in time t

(A full description of all the variables and data is given in the appendix at the end of this chapter)

Referring back to chapter 4, the appearance of the three economic variables in equation 5.3 is a consequence of the nature of the model. Individuals possess characteristic Z_i and acquire at the first date when $Z_i > Z_t^*$, where Z_t^* is the critical value of Z . This critical value occurs at the point where the marginal owner's perceived

discounted total benefit of ownership (dependent upon advertising and given preferences) is equal to the cost (represented by relative price, given myopic price expectations).⁷

Diffusion occurs as changes in the explanatory variables move the critical value along the distribution of Z , as in the diagram below.



The functional form of Z_t^* is not imposed *a priori*, rather, various empirical experimentations with the specification will be undertaken. For example both levels and logarithms of the variables will be tried. Another important area for investigation will be the lag structure of the advertising variable in this function, (for the reasons already outlined).

Unlike the variables on the RHS of equation 5.3, the precise functional nature of the dependent variable Y_t is imposed at the outset. This results from the assumed sech squared distribution of Z and consequent mathematical manipulation. This particular distribution (which is simply the corresponding probability density function of the logistic cumulative function) has been chosen primarily for practical reasons of mathematical and

⁷. The question of the use of the cost of acquisition or rental charges in the empirical investigation has already been discussed in chapter 4.

statistical ease.¹ However, as there are many factors which can influence an individual's judgement of the relative advantage of the new product (the compensation ratio) such a distribution would not seem unreasonable.

Initially, equation 5.3 (in which Z^*_t is a simple linear function of the economic variables in time t) is estimated by OLS and the results given in Table 5.E. Whilst the price and advertising variables have the expected negative and positive coefficients respectively, the coefficient on the interest rate variable is surprisingly positive. However the diagnostic tests provide evidence of the suspect nature of the model's specification. Re-estimating, using logarithmic transformations of the explanatory variables in Z^*_t instead, did not improve matters.⁹

The poor performance of this particular equation is not too surprising. After all, equation 5.3 is a static equilibrium relationship. It assumes that the adjustment by the new marginal owner, as indicated by the relative position of the critical value function Z^*_t to the distribution $f(Z)$, will take place immediately. Yet there are a number of real world constraining factors which need to be taken into account. Given the objective is to obtain a statistically robust model, a practical approach will be adopted, thus any refinements will not be derived in a rigorous fashion from the theoretical model.

The budget constraint facing the individual decision maker is one important factor to be considered. Diagram A5.4 in the appendix to this chapter clearly shows that the chosen income variable does not remain constant over the period. So per capita real disposable income, MY_t , is added to the RHS of the basic equation 5.3. Strictly, as the model is concerned with diffusion of the product between households, the appropriate variable should be real disposable household income but data availability restricts use to

1 Alternative distributions could be assumed however the resulting equation would no longer be amenable to OLS estimation. Given the relative small sample size and limitations in the quality of the data, use of more sophisticated techniques is unlikely to lead to superior results.

9. As the real rate of interest took some negative values over the period, it was necessary to first transform this variable to establish a positive series. This was simply done by subtracting the real rate of interest from some appropriate constant, ie, $LR = \log(10 - RR)$. Obviously, the expected coefficient on this variable will now be positive.

per capita income instead. The relevant household variable is represented by the number of colour television licences in force TVL_t , for the reasons already discussed earlier in this chapter.

The outlay involved for a consumer durable is often of considerable size in relation to an individual's flow of income. Consequently the availability of credit is likely to be a further constraining factor upon the simple relationship postulated in equation 5.3. Therefore a variable representing the minimum legal percentage down payment is also included. As previously explained, this variable took only two values over the period, (20% prior to 1982q3 and zero thereafter), a dummy variable HPD_t is used to proxy these restrictions. Previous studies (eg. Williams 1972) have also included the maximum monthly repayment period. As movements in this repayment period were correlated with the percentage down payment, the simple dummy variable was employed as a proxy variable.

Perhaps the single most important feature of the epidemic model is the emphasis upon the lack of information hindering the diffusion process. In contrast, the majority of probit based models neglect this factor (and as explained in chapter 2, to allow for this in an empirical model in any rigorous manner can be rather complicated). The model developed in chapter 4 effectively assumes partial information, individuals in the population are aware of the existence of the new generic product, but not of all its inherent characteristics. So advertising, by providing greater information about these specific features, leads all individuals to revise upwards their perceived valuation of the new product. Failure to recognise that members of the population may have no knowledge about the product at all, is likely to be most severe over the very early period of the diffusion process. It may therefore be necessary to revise the model in an informal manner later on.

The modified estimating equation is as follows:-

$$Y_t = \gamma_0 + \gamma_1.A_t + \gamma_2.P_t + \gamma_3.R_t + \gamma_4.MY_t + \gamma_5.HPD_t + \sum_i \gamma_i.Q_{it} + u_t$$

$$\gamma_1 > 0 \quad \gamma_2 < 0 \quad \gamma_3 < 0 \quad \gamma_4 > 0 \quad \gamma_5 < 0 \quad 5.3.1$$

$$Y_t = \kappa_0 + \kappa_1 \log(A)_t + \kappa_2 \log(P)_t + \kappa_3 \log(AR)_t + \kappa_4 \log(MY)_t \\ + \kappa_5 \text{HPD}_t + \sum \kappa_i Q_{it} + u_t$$

$$\kappa_1 > 0 \quad \kappa_2 < 0 \quad \kappa_3 > 0 \quad \kappa_4 > 0 \quad \kappa_5 < 0 \quad 5.3.2$$

where the variables are as previously described in the text and

$AR = 10 - R$ (transformed to provide a series with only positive values).

The results are given in Table 5.E. The additional variables MY and HPD have their expected positive and negative effect respectively. However, problems still remain with the perverse signs of the coefficient on the interest rate variable. Once again the diagnostic tests indicate serious mis-specification, so little credence should be given to the t statistics or improvement in R^2 and RSS of this particular structure relative to equation 5.3. Model 5.3.2 using logarithmic transformations of the explanatory variables did not produce any better results (although it is interesting to note that whilst still falling within the reject region, the functional form Reset test statistic is reduced considerably).

5.3.2 Extending the Dynamics; Stock of Goodwill

Given the static nature of models 5.3.1 and 5.3.2, the rejection of the DW statistic and LM tests for autocorrelation may be an indication of poorly specified dynamics in the equation. In chapter 4, it was suggested that the lagged effects could enter directly into the model using Nerlove and Arrow's stock of goodwill concept. Consequently, the effect of advertising will be cumulative on the re-evaluation of the flow benefit of ownership perceived by all individuals, (see figure 7 in chapter 4). The approach to the appropriate lag structure on the advertising variable, will be treated in the same fashion as in the estimation of the epidemic equation in the previous section.

Initially, additional lagged advertising variables are included directly into equation 5.3.1 and 5.3.2. Once again only 4 lags are included at the start due to practical

TABLE 5.E

OLS Estimation of the Probit Model.
Dependent variable, $Y_t = \log(X_t / TVL_t - X_t)$

MODEL 5.3		MODEL 5.3.1	MODEL 5.3.2	
CONS	-1.7066 (0.6764) **	-12.1673 (3.3415) **	CONS	5.4254 (25.6960)
P_t	-0.0149 (0.2645E-02) **	-0.7440e-02 (0.2002e-02) **	LP_t	-2.2736 (0.3868) **
A_t	0.9440e-04 (0.1594e-03)	0.2594e-03 (0.1041e-03) **	LA_t	-0.0287 (0.1785)
R_t	0.3036 (0.0516) **	0.1130 (0.0427) **	LR_t	-0.8598 (0.2373) **
MY_t		0.0115 (0.3321e-02) **	LMY_t	0.7199 (3.4142)
HPD_t		-1.6457 (0.2979) **	HPD_t	-1.0040 (0.2699) **
Q_{1t}	0.3390 (0.5021)	0.9578 (0.3475) **	Q_{1t}	0.1152 (0.3536)
Q_{2t}	0.1652 (0.4577)	0.6445 (0.3018) *	Q_{2t}	0.0515 (0.2779)
Q_{3t}	0.1521 (0.5188)	0.6178 (0.3420) *	Q_{3t}	-0.0657 (0.3205)
NOB	40	40	NOB	40
RSS	23.8907	8.3883	RSS	5.3330
DW	0.7266	0.6631	DW	0.6884
AR^2	0.8082	0.9283	AR^2	0.9544
LM4	Reject	Reject	LM4	Reject
RSET	Reject	Reject	RSET	Reject
NORM	Reject	Accept	NORM	Accept
HET	Reject	Reject	HET	Reject

Standard errors in parentheses.

*, ** denotes significance at 5% and 1% respectively.

considerations. The results are given in Table 5.F and labelled model 5.3.1b. Relative price and the HP restrictions variable have the usual negative effect. Likewise, income and current advertising have an expected positive influence on the dependent variable. Unfortunately the real rate of interest variable remains perversely positive. Of course, it may be that this variable is picking up the macro effects of its use as a policy instrument. Particularly over this period, the interest rate was used to control inflation arising from excessive demand in the economy. The endogeneity of this variable may therefore be causing problems. Also, previous work on expenditure on consumer durables have found that an interest rate variable was insignificant unless account was taken of bank borrowing with a switching regime to represent periods of supply and demand constraints (Mean 1979), whilst Cuthbertson (1980) found that a real interest rate variable was only important when a liquid assets variable was also included in the equation. The additional lagged advertising variables also have an unexpected effect, as shown by the negative coefficients on these variables. However, many of the unusually signed coefficients of the economic variables are not statistically significant, although the reliability of the standard errors of the estimated parameters cannot be trusted because of the possible presence of autocorrelation. The DW statistic falls within the inconclusive region but doubt is confirmed by a LM test which rejects the null hypothesis of no serial correlation up to order 4 in the error terms.

Using logarithmic transformations of all of the explanatory variables resulted in most of the lagged advertising variables having the expected positive signed coefficients. However in addition to possible problems with autocorrelation, the failure of the Reset would seem to indicate that transforming all of the variables in this particular manner way was not relatively beneficial. The results are therefore not reported.

It is worth pursuing a model in which the only explanatory variable to enter in logged form is advertising. It is interesting to note that in this model (5.3.1c in Table 5.F) the Reset test is accepted, suggesting this particular functional specification is superior to one in which all explanatory variables are logged. However it does not necessarily imply

TABLE 5.F

OLS Estimation of the Probit Model.
 Dependent variable, $Y_t = \log(X_t / TVL_t - X_t)$

MODEL 5.3.1b		MODEL 5.3.1c	
CONS	-2.8249 (3.0655)	CONS	-8.5613 (4.4436) *
P_t	-0.0316 (0.3187e-02) **	P_t	-0.0301 (0.3319e-02) **
A_t	0.7260e-04 (0.6270e-04)	LA_t	0.1927 (0.1111) *
R_t	0.1651 (0.0250) **	R_t	0.1712 (0.0243) **
MY_t	0.3830e-02 (0.2877e-02)	MY_t	0.8214e-02 (0.2871e-02) **
HPD_t	-0.7550 (0.2943) **	HPD_t	-0.4434 (0.2354) *
Q_{1t}	0.3640 (0.2561)	Q_{1t}	0.7282 (0.3631) *
Q_{2t}	0.2232 (0.2037)	Q_{2t}	0.1748 (0.2090)
Q_{3t}	0.2036 (0.2564)	Q_{3t}	0.5791 (0.3706)
A_{t-1}	-0.670e-04 (0.7350e-04)	LA_{t-1}	-0.0844 (0.1166)
A_{t-2}	-0.464e-04 (0.7450e-04)	LA_{t-2}	0.1944 (0.1274)
A_{t-3}	-0.774e-04 (0.6820e-04)	LA_{t-3}	-0.1562 (0.1139)
A_{t-4}	-0.448e-04 (0.7150e-04)	LA_{t-4}	0.1766e-02 (0.1217)
NOB	36	NOB	36
RSS	1.5939	RSS	1.4414
DW	1.2468	DW	1.2125
AR^2	0.9756	AR^2	0.9779
LM4	Reject	LM4	Reject
RSET	Accept	RSET	Accept
NORM	Accept	NORM	Accept
HET	Accept	HET	Accept

Standard errors in parentheses.

*, ** denotes significance at 5% and 1% respectively.

that this is the most suitable functional specification. Indeed the failure of the LM test detecting autocorrelation up to order four could be highlighting this point. Leaving that aside, relative to model 5.3.1b, more of the lagged advertising variables now have a positive coefficient but still remain statistically insignificant.

There seems very little to choose between these specifications. As already suggested, the failure of the LM test does not mean the error terms are truly autocorrelated. It is much more likely a sign of a mis-specified model, in particular, the dynamics could be wrong. The number of lags of the advertising variable so far has been limited. Thus further investigation of the lag distribution of this particular variable will be undertaken. Whether the other explanatory variables should have lasting effects also needs to be considered. For example the permanent income hypothesis would see a role for the inclusion of lagged values of income. When convenient these additional dynamic factors will be incorporated but given the interests of this study, the weight of effort will centre on the dynamics of the advertising variable.

If the lasting effects of advertising in the Z^* function are of an infinite geometrically declining nature, then after substitution into equation 5.3.1, a Koyck transformation can be performed. The results are labelled model 5.3.3 in Table 5.G. The LM test accepts the null hypothesis of no autocorrelation up to order 4. However Durbin's h statistic, (which is the appropriate statistic to use when testing for first order autocorrelation in the presence of a lagged dependent variable on the RHS of the equation) rejects the null hypothesis but only at the 5% level of significance. Given the simultaneous existence of a lagged dependent variable in the explanatory variables and serially correlated error terms, the estimated parameters will be biased and inconsistent.

The Reset test is rejected, casting further doubt on the chosen specification. In addition to these statistical misgivings, the poor performance of some of the variables in economic terms, provides further evidence against this particular model (subject to the caveat regarding the robustness of the estimated parameters if autocorrelation is present).

Whilst current advertising has a positive effect and price a negative one, the income variable and HP dummy variable no longer perform as expected. However previous empirical investigations of diffusion curves have often found the results unsatisfactory when both a price and income variable are included in the model (Chow 1967, Bain 1962).

If the Koyck transformation procedure is appropriate, the estimated coefficient on the first lag of a variable should equal the coefficient on the respective current variable multiplied by the coefficient on the lagged dependent variable. In order to obtain unique estimates of the structural parameters, a number of non linear restrictions will apply and should be tested. This would require use of a more sophisticated non linear estimation procedure. However an informal glance at the estimated size of the coefficients shows that especially for the price and income terms, these constraints are unlikely to hold.

A further problem concerns the magnitude and significance of the coefficient on the lagged dependent variable. A value of $1 - 0.9803$ indicates a very slow rate of decay on the advertising variable, which given previous results and the existing literature, seems questionable despite the durable nature of the product being investigated. The domination of this variable in the equation is also disquieting, although previous researchers have found the same effect in their empirical diffusion equations (Chow 1967, Stoneman 1976). Incidentally, assuming a geometric declining lag structure for all the economic variables gives an estimating equation in which only the current values of the explanatory variables enter as well as the lagged dependent variable (model 5.3.3B). As can be seen, this does not improve matters either statistically or on economic criteria. The lagged dependent variable eclipses the other more interesting variables and again the perverse coefficients on the income and HP terms are perturbing. Altogether the conclusion must be reached that an infinitely declining lag structure either for advertising uniquely or common to all variables, is not appropriate.

The next stage will be to investigate an Almon lag structure on the advertising variable. A maximum of 8 lags was included with an assumed third degree polynomial. As the finite lag structure must be chosen arbitrarily, it is worth experimenting with the maximum lags. These were gradually reduced down to 4 lags. In order to choose the most appropriate specification the equation producing the lowest RSS could be used. However the diagnostic test statistics indicate the possibility of autocorrelation in the model, consequently the estimated RSS will be unreliable. So this criterion was tempered by economic considerations.

On balance, a lag length of 6 quarters looks most suitable and the results for model 5.4 are shown in Table 5.G. Most of the explanatory variables have the expected sign (except for the real rate of interest which is persistently positive). None of the coefficients of the composite advertising variables W_i are statistically significant, including W_0 which represents current advertising. Providing all explanatory variables are exogenous, the possible existence of autocorrelation will render the estimated standard errors inefficient, but the estimated coefficients will still remain unbiased and consistent. Given the estimated coefficients, the structural parameters on the advertising variables are as follows (although the estimated variance of these parameters could be calculated, it was not considered worthwhile due to the likely contamination),

$$\begin{aligned}
 a_0 &= 0.225e-04 & a_1 &= -0.506e-04 \\
 a_2 &= -0.673e-04 & a_3 &= -0.450e-04 \\
 a_4 &= -0.11e-05 & a_5 &= 0.470e-04 \\
 a_6 &= 0.819e-04
 \end{aligned}$$

The negative coefficients on lag 1 2 3 and 4 do not make economic sense and coupled with the possibilities of autocorrelation in the model (the DW statistic falls

TABLE 5.G

OLS Estimation of the Probit Model.
Dependent variable, $Y_t = \log(X_t / TVL_t - X_t)$

MODEL 5.3.3			MODEL 5.3.3B			MODEL 5.4		
CONS	0.7193 (0.4018) *		0.8305 (0.3649) *			CONS	-3.1915 (3.0006)	
P_t	-0.1369e-02 (0.1411e-02)		-0.6320e-03 (0.4278e-03)			P_t	-0.0386 (0.7161e-02) **	
A_t	0.1310e-04 (0.1010e-04)		0.1380e-04 (0.9600e-05)			W_{0t}	0.2250e-04 (0.6840e-04)	
R_t	0.3040e-02 (0.6729e-02)		-0.7916e-03 (0.5454e-02)			R_t	0.1500 (0.0281) **	
MY_t	-0.8942e-03 (0.5434e-03) *		-0.6903e-03 (0.3571e-03) *			MY_t	0.4498e-02 (0.2726e-02)	
HPD_t	0.0681 (0.0398) *		0.0769 (0.0370) *			HPD_t	-0.3467 (0.3469)	
Q_{1t}	-0.0986 (0.0386) **		-0.0908 (0.0336) **			Q_{1t}	0.2317 (0.1800)	
Q_{2t}	-0.1030 (0.0306) **		-0.1040 (0.0288) **			Q_{2t}	0.1196 (0.2118)	
Q_{3t}	-0.0597 (0.0322) *		-0.0577 (0.0310) *			Q_{3t}	0.1481 (0.1981)	
Y_{t-1}	0.9803 (0.0245) **		0.9887 (0.0216) **			W_{1t}	-0.1071e-03 (0.1102e-03)	
P_{t-1}	0.4275e-03 (0.7984e-03)					W_{2t}	0.3680e-04 (0.4260e-04)	
R_{t-1}	-0.3203e-02 (0.5383e-02)					W_{3t}	-0.2900e-05 (0.4600e-05)	
MY_{t-1}	0.3401e-03 (0.5357e-03)							
NOB	39		39			NOB	34	
RSS	0.0538		0.0566			RSS	1.5471	
DW	2.0780⁺ +(h.stat)		2.7340⁺ +(h.stat)			DW	1.4182	
AR²	0.9994		0.9994			AR²	0.9752	
LM4	Accept		Reject			LM4	Reject	
RSET	Reject		Accept			RSET	Accept	
NORM	Accept		Accept			NORM	Accept	
HET	Accept		Accept			HET	Accept	

Standard errors in parentheses.

*, ** denotes significance at 5% and 1% respectively.

within the inconclusive region but a LM test assuming no serial correlation up to order 4 is rejected) this particular structure must be abandoned.

5.3.3 Advertising and Competition

When discussing the epidemic model, it was suggested that the true advertising response coefficient may have altered during the period 1982 as a result of increased competitive advertising. In order to capture this effect, a multiplicative dummy variable was constructed. Repeating this procedure for the probit model gives,

$$\gamma = (e_0 + e_1 D_t) A_t \quad D = 1 \text{ in 1982, 0 otherwise}$$

$$\text{and } e_0 > 0, \quad e_1 < 0$$

The results were not very satisfactory and so are not reported. The coefficient on the multiplicative dummy term, e_1 , was positive but insignificant. The other variables had their expected signs (except the rate of interest). However the failure of LM up to order 4, Reset, and heteroscedasticity diagnostic tests, strongly indicate mis-specification in the model.

5.2.4 Hire Purchase Restrictions

Similarly, some consideration was given to the HP dummy variable. So far, it has been included in an additive way. However, the effect of HP restrictions could be to constrain the true marginal response coefficients of the explanatory variables. If so, then,

$$Z_t^* = \phi_0 + \phi_1 A_t + \phi_2 P_t + \phi_3 R_t + \phi_4 MY_t$$

and

$$\phi_{1t} = f_0 + f_1 HPD_t$$

$$\phi_{2t} = h_0 + h_1 HPD_t$$

$$\phi_{3t} = j_0 + j_1 HPD_t$$

$$\phi_{4t} = k_0 + k_1.HPD_t$$

5.3.5

The results from estimation of this equation are given below.

$$\begin{aligned}
 Y_t = & -2.99 - 0.441.P_t + 0.443e-04.A_t + 0.111.R_t \\
 & (5.426) \quad (0.0182)^* \quad (0.118e-03) \quad (0.087) \\
 & + 0.465e-02.MY_t + 0.519.Q_{1t} + 0.204.Q_{2t} + 0.243.Q_{3t} \\
 & \quad (0.483e-02) \quad (0.342) \quad (0.296) \quad (0.325) \\
 & + 0.035.PHPD_t + 0.365e-03.AHPD_t - 0.09.RHPD_t \\
 & \quad (0.017)^* \quad (0.149e-03)^* \quad (0.104) \\
 & - 0.495e-02.MYHPD_t \\
 & \quad (0.131e-02)^{**}
 \end{aligned}$$

$$NOB = 40 \quad RSS = 5.8333 \quad DW = 0.746 \quad AR2 = 0.945$$

$$LM4 = REJECT \quad RSET = ACCEPT \quad NORM = ACCEPT \quad HET = REJECT$$

The specification looks suspect as indicated by the failure of the autocorrelation test statistics (DW and LM4) and heteroscedasticity test. On economic criteria, the robustness of the model is questionable. When HP restrictions are in force, the marginal response of advertising should be lower. So the coefficient on the multiplicative dummy term will be negative but this estimated coefficient is positive. The price variable behaves better, having a negative coefficient. During periods of credit control, the effectiveness of a fall in price on the dependent variable may be reduced. Thus $\phi_{2t} = (-0.0441 + 0.035) = -0.0091$.

The income variable has a positive coefficient during the period of credit restrictions. However when HP controls apply, the effect of income on the dependent variable is reduced but to such an extent that the overall coefficient ϕ_{4t} becomes negative. This is economically feasible but highly implausible.¹⁰ It is much more likely

10. This would imply that a VCR is an inferior good. It has been argued that the recreation of television viewing is a cheap form of entertainment. Therefore since this product allows the substitution of this cheaper

that the model is mis-specified as indicated by the failure of the diagnostic tests especially since a positive coefficient on the income variable had been found in the models estimated earlier.

5.3.5 Preliminary Conclusions

The results for the probit model so far, are not very encouraging. None of the models estimated give confidence either in terms of statistical criteria or economic interpretation. Various ad hoc experiments with lags of variables other than advertising were tried but without success. The magnitude and significance of the coefficients estimated were particularly sensitive to the precise probit specification adopted. Throughout the real rate of interest variable had a positive and strongly statistical significant coefficient, yet theory would suggest a negative influence on the dependent variable (although given the qualifications mentioned above), giving concern about the model specification. Inclusion of a lagged dependent variable provokes further scepticism. The domination of this particular variable to the detriment of the remaining economic explanatory factors, coupled with the implausibility of the implied rate of decay does cast doubt upon this particular model. Although this variable could be picking up the word of mouth or bandwagon effect, especially since the epidemic model estimated suggested that information passed by existing owners was particularly important.

5.3.6 A Stock Adjustment Model

There are various possible reasons for the failure of the models. The quality of the data being used may be inadequate. Certainly there are problems (as discussed in the appendix), but this is true of most empirical work. However it is advisable to investigate the diffusion of another new consumer durable, preferably one for which a better data set can be established. Then a better judgement can be made about the extent to which the poor performance indicated in this chapter is partially attributable to an inferior data set.

form of entertainment (including pre recorded films as opposed to cinema visits) this effect may be arising. Interestingly, market research has shown that on a demographic basis, the greatest proportion of ownership/rental of a VCR is among the C2 socio economic class. This is in contrast to other major consumer durables where class A and B have the largest proportion of ownership.

Leaving data problems aside, other difficulties could be arising because the true theoretical structure has not been modelled accurately. At the beginning of the probit section, the failure to account for the number of individuals in the potential population who are totally ignorant of the product was noted. Ideally a combination of the two competing structures would overcome this drawback. Unfortunately such an approach can only be attempted informally but at the expense of losing much of the detail of the epidemic and probit models. For example, by using a stock adjustment equation

$$X_t - X_{t-1} = \lambda(X_t^* - X_{t-1})$$

where

X_t = stock of VCRs in time t

X_t^* = $f(A, P, MY, R, HPD)$, the equilibrium stock of VCRs, justified on the grounds described in the derivation of the probit model in chapter 4.

λ = an adjustment parameter, required because of lack of information in the population. This will in turn be a function of the existing stock of the product (based on the usual epidemic reasoning). Ideally advertising should also be included but this adds to the complexity of the model and it is unlikely that the two effects of advertising in λ and X_t^* , can be disentangled by the data.

If the assumption is made that $\lambda = L.X_{t-1}$, and X_t^* is a simple linear function of the economic variables, then the equation becomes,

$$\frac{X_t - X_{t-1}}{X_{t-1}} = d_0L + d_1L.A_t + d_2L.P_t + d_3L.R_t + d_4L.MY_t + d_5L.HPD - L.X_{t-1}$$

The results for this equation (including seasonal dummies) given in Table 5.I, are not very promising. The diagnostic tests indicate mis-specification and many of the economic variable have a perverse sign. In this form of course, the equation is equivalent to the logistic based model used by Chow (1967), or Bain (1962). Following the Chow

TABLE 5.1

OLS Estimation of a Stock Adjustment Model.
 Dependent variable, $GRO_t = (X_t - X_{t-1}) / X_{t-1}$

MODEL 5.4A		MODEL 5.4B	
CONS	0.9011 (0.6690)	CONS	10.8751 (2.5277) **
P_t	-0.4981e-03 (0.2996e-03)	LP_t	-0.1737 (0.0704) **
A_t	-0.1000e-06 (0.1100e-04)	LA_t	-0.0157 (0.0171)
R_t	-0.5900e-03 (0.6004e-02)	LR_t	0.3874 (0.0301)
MY_t	-0.6837e-03 (0.7331e-03)	LMY_t	-1.4063 (0.3246) **
HPD_t	0.0989 (0.0398) **	HPD_t	0.9204 (0.0307) **
Q_{1t}	-0.1051 (0.0422) **	Q_{1t}	-0.1208 (0.0335) **
Q_{2t}	-0.1214 (0.0348) **	Q_{2t}	-0.1260 (0.0270) **
Q_{3t}	-0.0867 (0.0369) *	Q_{3t}	-0.0990 (0.0308) **
X_{t-1}	-0.970e-05 (0.9400e-05)	LX_{t-1}	-0.0328 (0.0223)
NOB	39	NOB	39
RSS	0.0766	RSS	0.0441
DW	1.3536	DW	1.3638
AR^2	0.7719	AR^2	0.8155
LM4	Accept	LM4	Accept
RSET	Reject	RSET	Reject
NORM	Reject	NORM	Accept
HET	Reject	HET	Accept

Standard errors in parentheses.

*, ** denotes significance at 5% and 1% respectively.

approach further, using logarithms of the explanatory variables, based on a Gompertz hypothesis, gives slightly better results as shown in Table 5.I. However the diagnostic tests still give cause for concern regarding the model specification. Once again the advertising, income and HP variable behave badly, having unexpected signs. Allowing the adjustment function to be a function of advertising too, could be pursued, however, as indicated above (and based upon some provisional and unfruitful results for another product, not reported here), such a refinement was not considered worthwhile.

5.3.7 Simultaneous Equation Bias

Finally some consideration must be given to the potential simultaneous bias in the estimated equations. The estimation of the structural demand diffusion model in this chapter, whether based upon the epidemic or probit structure, effectively assume away any simultaneity between the advertising and stock variable. Yet the models developed in chapters 3 and 4 assume that advertising is a decision variable. Ignoring this endogeneity in the OLS estimation, will lead to biased and inconsistent estimates. If the bias is positive, this will result in an over estimation of the advertising coefficient. However Schmalensee (1972) points out that advertising decisions may take place before the level of sales are known, so expectations of sales will be the appropriate variable to include in the advertising equation. In this case, the direction of the bias may be negative (as the covariance between the two structural equations in the model will be negative), so under estimating the true effect of advertising.

Consequently a simultaneous equation model should be established using the additional advertising appropriations equation derived in the earlier chapters.¹¹ This procedure is not adopted for this particular product due to data limitations. However some attempt is made to estimate a simultaneous model in the next chapter. Further discussion will therefore be reserved until this time, except to note that given the use of

¹¹ Strictly, an equation should also be established for price but as the focus of attention in this thesis is directed towards the advertising variable, the added complication will be ignored.

quarterly data, assuming away the simultaneity between advertising and current sales may not be too implausible, thus allowing the use of OLS estimation.

5.4 CONCLUSIONS: THE VIDEO CASSETTE RECORDER

The epidemic based model, especially with advertising entering indirectly through the social contact coefficient, produced some interesting results. The magnitude of the coefficient on the existing ownership variable was sensitive to the choice of the advertising information channel adopted. This emphasises how important it is to empirically investigate the chosen structure if accurate estimates of the effect of the variables are to be obtained. However, within a specification, the performance of this variable, in terms of magnitude and statistical significance, was consistent and did appear to be an important explanatory factor in the diffusion process. Similarly, the current advertising variable also appeared to be important but its effect was indirect by temporarily increasing the social contact coefficient. Given that the VCR was a radically new good in the sense that no previous substitute existed, the importance of the spread of information as indicated by the epidemic model may be quite reasonable, especially in the early period. However the predictive ability of the epidemic model proved disappointing. It is quite likely that this is due to the failure to incorporate other economic variables which may take on added importance later in the product life cycle. The benefit from including a HP interactive term in the epidemic model could be hinting at this omission.

Unfortunately, the alternative probit based model did not perform too well. The magnitude and statistical significance of the coefficient on the economic variables was particularly sensitive to the model structure. Once a lagged dependent variable was included, this variable dominated the equation (of course the model structure still remained suspect given the failure of one of the diagnostic statistics). In fact, this explanatory variable could be picking up the word of mouth effect, especially given the success of the existing ownership variable in the epidemic model.

APPENDIX A5

THE VARIABLES AND DATA

BACKGROUND

The first year in which the Video Cassette Recorder (VCR) was sold in significant numbers to the UK consumer market was 1978. Prior to this, most VCRs sold were primarily for institutional users and the relative price of this product was some two to three times that of the VCR designed and introduced for household use. However it would be unrealistic to assume that no stock existed amongst households at the beginning of 1978 since this completely new product had been available from the mid 1970s. Therefore in the empirical investigation presented in the chapter, the initial opening stock of VCR in 1978 quarter 1 in the UK was estimated, using various market research reports, to be approximately 43000 sets.

Initially there was no product standardisation, with three competing types of VCR, namely Betamax, VHS and Philips VCR (this became V2000 format in 1979). This paper assumes a homogeneous product as no attempt is made to examine the diffusion of the various types of VCR. However it is quite possible that this lack of uniformity in industry standards slowed down the diffusion process especially in the early years. In such circumstances, a consumer's purchase decision would lock him into a specific technology and any change would involve switching costs (Porter 1976). Consumers would have to form expectations about the likely winner of the standards race and this would add to their uncertainty, especially before a clear leader was established (Grindley and McBryde 1988, Arthur 1989, Stoneman 1989). In fact the VHS format was always the market leader and by 1982/3 the trend in the share of the other two rival technologies was downwards. Industry estimates in 1983, gave the VHS standard 60% of market volume, whereas Betamax held 28%. Philips began selling a VHS format machine in the UK in 1984 and Sony finally acquiesced to the VHS format in 1988.

VCR CUMULATED STOCK (X)

The basic source of data on VCR sales, that is consumer offtake, was obtained from BREMA (The British Radio and Electronic Equipment Manufacturers' Association). The original data is UK market availability (UK production + imports - exports). This has been adjusted for changes in suppliers stock (trade deliveries) and retailers stock (from BREMA) to arrive at estimates more closely in line with true consumer offtake during the period and includes purchases by consumers and rental companies. During the early years prior to 1982, supply of VCR originated from overseas manufacturers. After this period, a fledgling UK production base was established, although predominantly of a 'screwdriver assembly' character, usually in Japanese owned plants.

Quarterly data on consumer offtake was available for 1980q1 to 1985q4. Annual figures only were available in 1978 and 1979. These yearly observations were adjusted using a seasonal factor calculated from the available quarterly series. Unfortunately BREMA were unable to supply consumer offtake figures for the final two years 1986 and 1987. Instead trade deliveries were used for these later observations. 1987 data was available on a quarterly basis, however the annual 1986 figure had to be adjusted using the seasonal factor described above. There is no *a priori* reason to expect retailers stock changes to move systematically in any one direction over a length of time (it is of course likely that these stocks would respond temporarily to cycles in consumer expenditure). No adjustment was made to these later observations for changes in retailer's stock, allowing instead any measurement error in the dependent variable to end up in the equation residual and have no effect on the estimated parameters.

The purpose of the empirical model is to explain the diffusion of first sets of VCR (whether purchased or rented). The consumer offtake data will include both replacement and multiple set purchases. No adjustment to the data has been made to alleviate these phenomena. It is likely that multiple set ownership during the period investigated was still fairly negligible especially since market research estimates of multiple tv ownership were still relatively low. Replacement purchases during the first 5

to 7 years are also unlikely to be significant. However after 1982/3, it is probable that the older units would be wearing out and coupled with technical obsolescence and updating to the standard winner, lead to some replacement demand within the data over the later period. Estimates of true household penetration are therefore likely to be lower than indicated by the data.

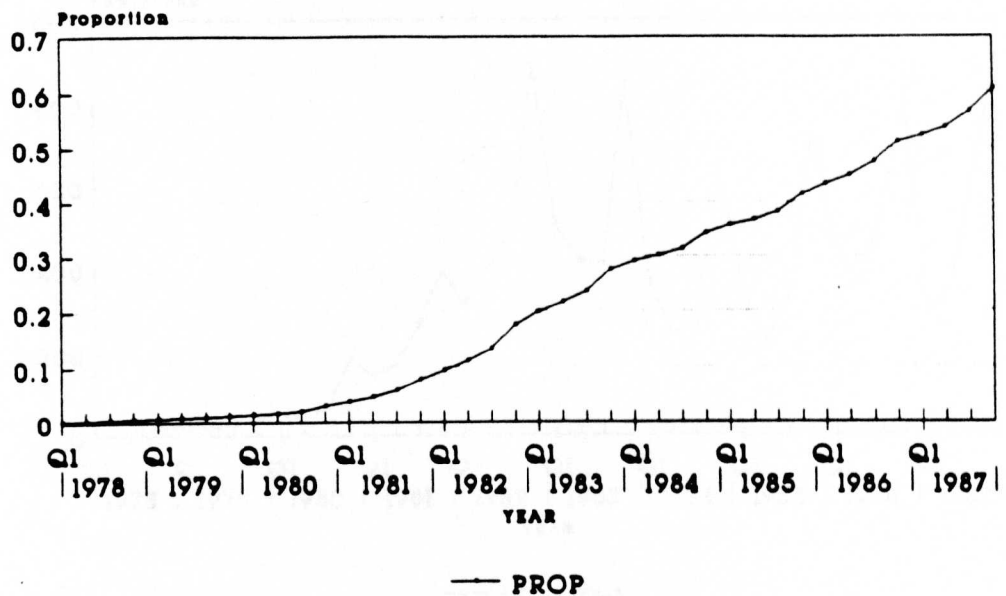
Figure A5.1 shows the cumulated consumer offtake of VCR as a proportion of UK households. By the end of 1979, the proportion of UK households renting or owning a VCR was only about 1%, by the end of 1987 this had increased to 60% . The consumer offtake data in figure A5.2 shows that this reached a peak in late 1982 early 1983. There are some indications that sales in 1987 are once again on an upward trend. This could be due to the inclusion of replacement and multiple purchases within the data. The seasonality of the data is clearly evident with quarter 4 showing the highest level of sales within a year. The rate of growth in stock also confirms that by 1982 the rapid spread of this product had ceased and a falling rate of growth was established. Strictly, the relevant potential population for this product is colour TV households due to the complementary nature of the products. Although if the purchase decision is simultaneous, then the proportion of demographic households will still be of interest. Figure A5.1 also shows the proportion of VCR ownership in colour TV households. The absolute ownership level will be higher since colour TV penetration was not 100% of households. However the trend in the two ownership graphs are very similar, as the growth in colour TV households was more or less constant over the period considered in this chapter (see next chapter for more detail).

The major explanatory variables in the investigation are each described in turn.

UK VCR OWNERSHIP

Proportion of UK Households Owning or Renting a VCR

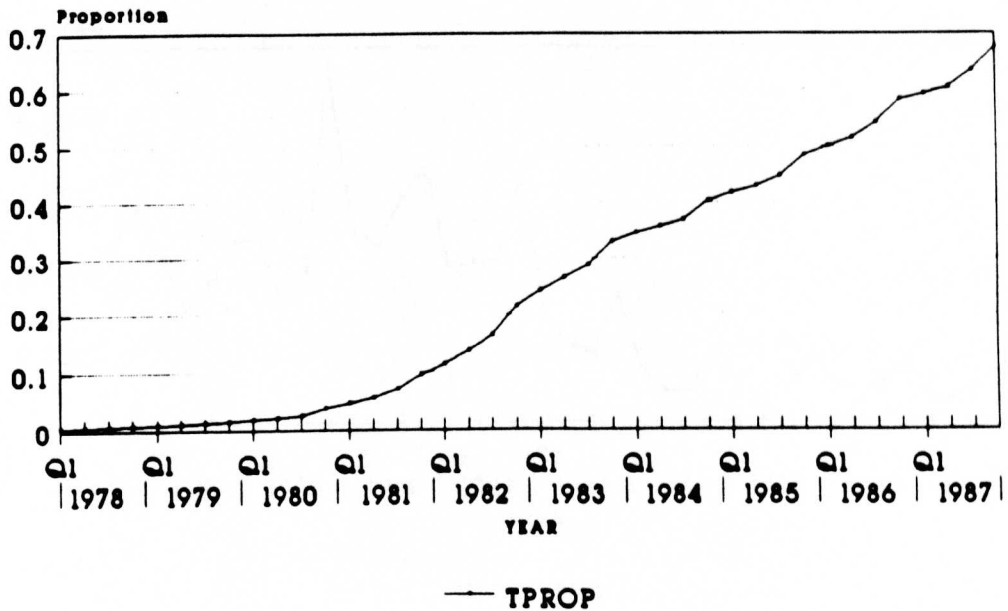
A5.1



Source: BREMA
PROP = XI / HH1

UK VCR OWNERSHIP

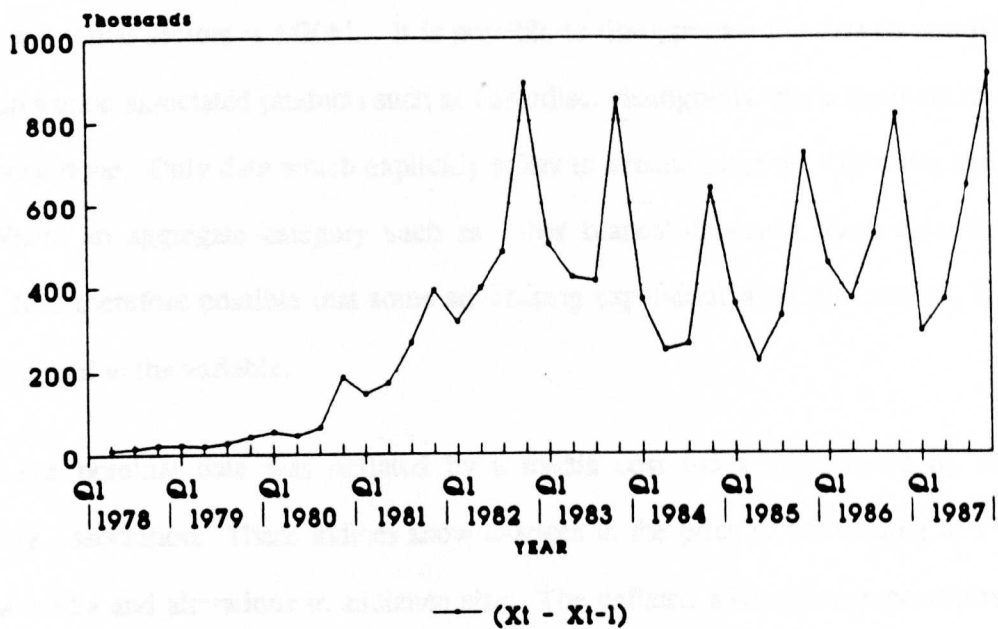
Proportion of UK Colour TV Households Owning or Renting a VCR



Source: BREMA
TPROP = XI / TVLI

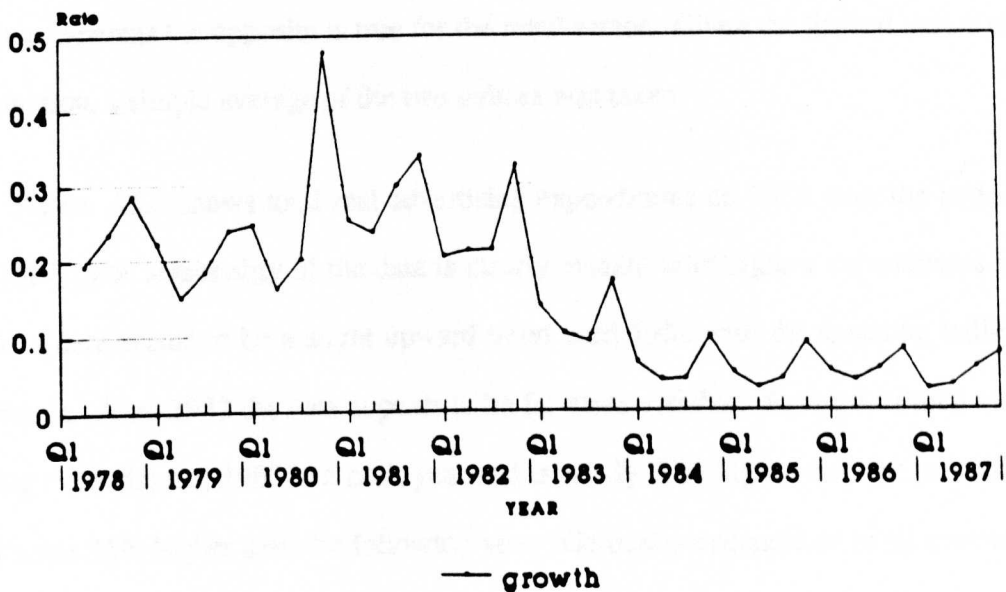
UK VCR SALES Consumer Offtake in units

A 5.2



Source: BREMA
Sales = $X_t - X_{t-1}$

UK GROWTH IN STOCK OF VCRs (Stock is measured by cumulated consumer offtake in units)



Source: BREMA
 X_t = cumulated UK consumer offtake, units
Growth = $(X_t - X_{t-1}) / X_{t-1}$

ADVERTISING EXPENDITURES (A)

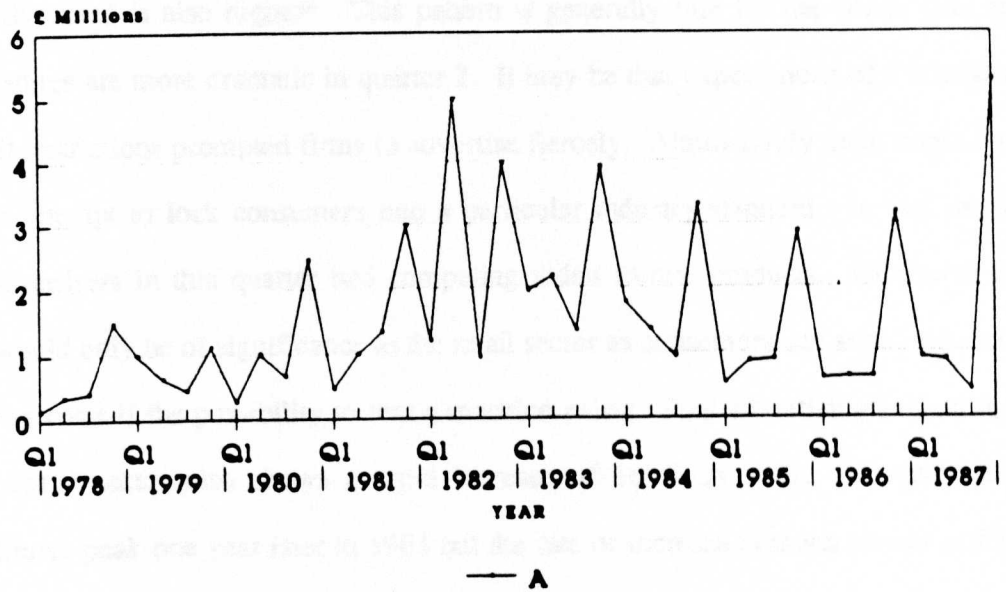
The basic source of data for total nominal advertising expenditures on VCR by the retail and rental sectors is MEAL. It is possible to disaggregate the data to remove expenditures upon associated products such as Laserdisc, videograms, blank tapes etc and this has been done. Only data which explicitly refers to expenditures on VCRs has been used. Where an aggregate category such as 'other brands' appeared, such data was ignored. It is therefore possible that some advertising expenditures on this product has been overlooked in the variable.

The nominal data was deflated by a media cost index constructed by the Advertising Association. These indices show changes in the price of advertising in TV and Press media and alterations in audience size. The deflated advertising expenditures should therefore represent the real volume of expenditures in these respective media. A simple average of both the separate Press and TV indices was taken. Some limited information was available on the share of VCR advertising in press and tv. On the whole the rental sector has a tendency to allocate a higher share of advertising expenditure to the Press sector, whereas the opposite is true for the retail sector. Given the limited nature of this information, a simple average of the two indices was taken.

Figure A5.3 shows total real advertising expenditures on VCR over the period 1978 to 1987. The seasonality of the data is clearly evident with highest expenditures in quarter 4. There seems to be a slight upward trend until 1982 with the spending tailing off afterwards. After 1982 the data appears to be far more variable. In terms of total real advertising expenditures, 1982 is a peak year and is nearly 70% higher than the previous year and some 55% higher than the following year. Generally expenditure in all quarters of this peak year is larger than in 1981, however much of the annual increase is accounted for in quarter 2 (almost 328% higher than 1981q2 and 239% higher than in this quarter in 1983).

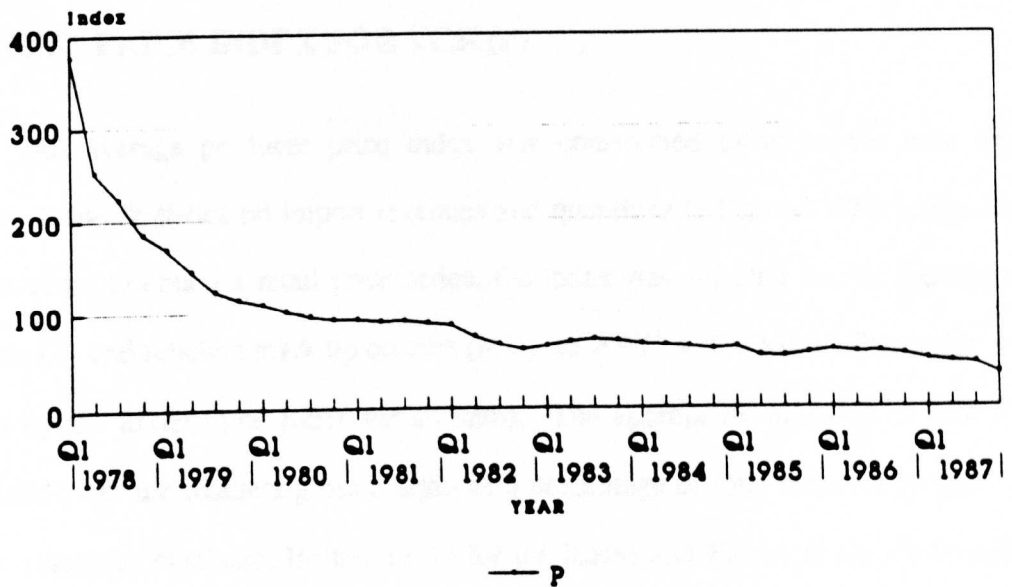
REAL ADVERTISING MESSAGES ON VCRs **Total Real Advertising Messages on VCRs** **by the Rental and Retail Sectors**

A 5.3



Source: MEAL and AA
A = (NA / MC180)x100

REAL AVERAGE RETAIL PRICE OF VCRs **Average Retail Price of VCRs** **deflated by Retail Price Index, 1980=100**



Source: Overseas Trade Statistics, BREMA
Retailing, Economic Trends
P = (ARP80 / RP180)x100

A closer inspection of the raw data reveals that in 1982q2 especially, not only are larger sums being expended on individual brands¹ but the overall number of brands being advertised is also higher². This pattern is generally true for the whole year and such features are more dramatic in quarter 2. It may be that expectations of a relaxation in credit restrictions prompted firms to advertise fiercely. Alternatively there might have been an attempt to lock consumers into a particular industry standard. In fact the top three advertisers in this quarter had competing video format products. Of course this factor would only be of significance to the retail sector as consumers can avoid expensive switching costs if the possibility to rent a machine exists. Real advertising expenditures in the rental sector also shows a rapid increase of 168% in 1982. However these expenditures peak one year later in 1983 but the rate of increase is much slower at 23%. Like the retail sector quarter 2 in 1982 has by far the largest annual rate of increase. Given the unusual increase in advertising is repeated in the rental sector too, it seems likely that the removal of hire purchase restrictions is the more important factor as this would affect both sectors.

RELATIVE PRICE INDEX FOR VCR (P)

An average producer price index was constructed using as the base data, Overseas Trade Statistics on import revenues and quantities (API) and 1980 as the base year. In order to obtain a retail price series, the index was adjusted for the appropriate VAT rate (T) and retailers mark up on cost (MU), so $API(1 + T + MU)$. This index was deflated by the Retail Price Index for all items. The appropriate mark up on cost was determined from the retailers gross margin as a percentage of total turnover (wages and salaries treated as overhead, Holton 1957) for the Radio and Electrical Goods Retailers excluding Hire³. The gross margin data was obtained from Retailing, initially on an

¹ Philips is the market leader in terms of advertising, with 42% of expenditure in this quarter compared to 20% in the same quarter in the previous year.

² 16 identifiable VCR brands compared to 6 in the previous year. The top three brands, Philips, Sony and Sanyo account for some 80% of advertising expenditure in 1982q2.

³ Since gross margin $\mu = (P-C)/P$ and mark up on cost $MU = (P-C)/C$, then $MU = 1/(1-\mu) - 1$.

annual basis but latterly on a biannual basis. Missing quarterly observations were therefore estimated by interpolation.

The constructed average price series may not give a true indication of the average price of VCR, since the original import data includes sets imported in kit form for assembly in the UK (this is obviously more significant from 1983 onwards) and it was not possible to disaggregate the data to remove this effect. However movements in the series will reasonably accurately reflect the trend in the relative price of VCRs.

Since the series is an average measure, changes in the sales mix of the product model range will not be distinguishable from an overall change in the price of the product. In other words, no account has been made for the fact that the 'bundle of characteristics' represented in models may be significantly changing over time. An observed higher unadjusted relative price may therefore be misleading, if the level of characteristics of the product has simultaneously increased. However over the ten years, any significant trend in the products overall relative price should still show up.

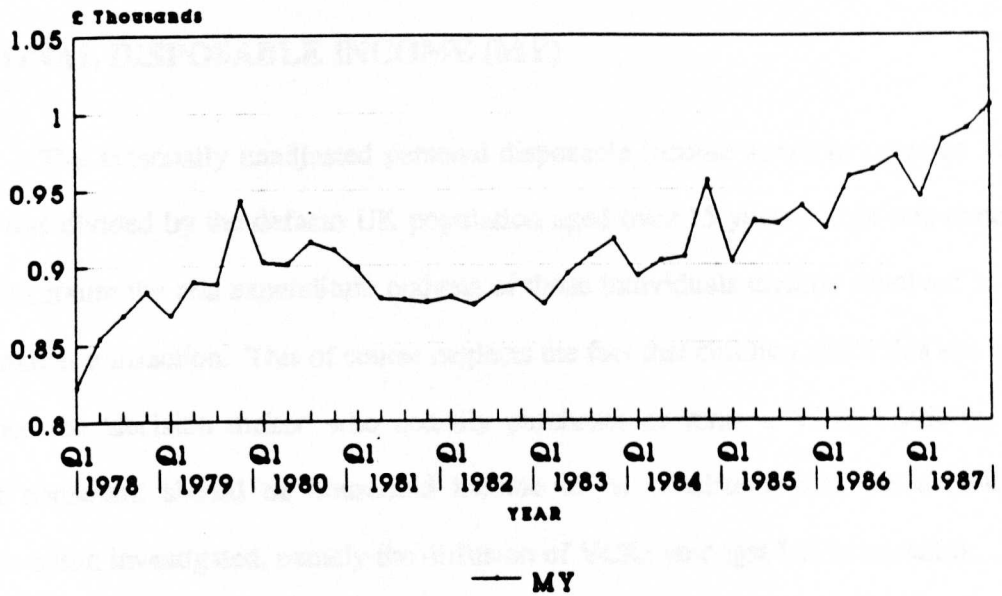
The graph in Figure A5.3 clearly shows a fall in the relative price of the VCR. The change is quite dramatic up to the end of 1980. Thereafter the trend is still downward but at a slower rate, with a sharp temporary fall in 1982. The reasons for the fall could be similar to those suggested for the increase in advertising in this period (especially the relaxation of credit controls) or it may be due to the inaccurate data mentioned earlier, as there was a change in situation with respect to the importation of kit form VCRs for assembly in the UK.

REAL INTEREST RATE (R)

The nominal 3 month treasury bill yield was the basic source of this series. This was then adjusted by the rate of inflation to give the real interest rate. Figure 4 shows the high positive rate of interest and its upward trend. The negative real rate of

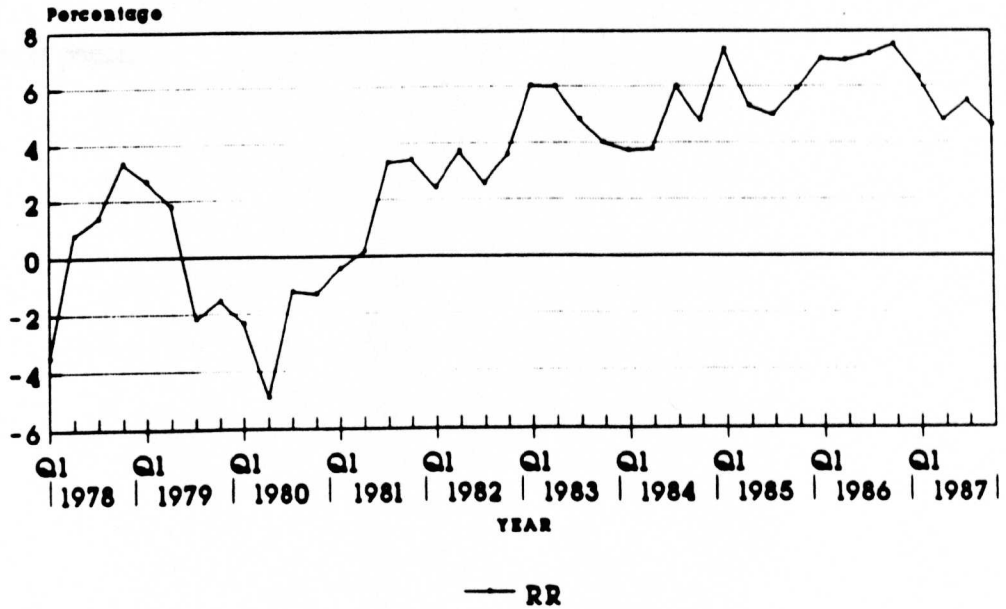
REAL PERSONAL DISPOSABLE INCOME **Per Capita Seasonally Unadjusted PDI** **Constant Prices 1980=100**

A5.4



Source: Monthly Digest of Statistics
 MY = PDI / POP

REAL RATE OF INTEREST **Nominal 3 month Treasury** **Bill Yield less Rate of Inflation**



Source: Financial Statistics
 RR = NTBY - INFL

interest in late 1979 to early 1981 is clearly a result of the high rate of inflation during this period.

PERSONAL DISPOSABLE INCOME (MY)

The seasonally unadjusted personal disposable income series in constant 1980 prices was divided by the defacto UK population aged over 15 years. This was done in order to capture the real expenditure budgets of those individuals directly involved in the VCR market transaction. This of course neglects the fact that children under this age may influence the 'decision maker' who actually purchases or rents a VCR. Strictly, the budget constraint should be household income to be consistent with the dependent variable being investigated, namely the diffusion of VCRs amongst UK households. The data series used was readily available on a quarterly basis and was therefore employed as an approximation. Figure A5.4 shows that the variable exhibited an upward trend, except for the recessionary effect of 1981/2.

A full description of all the variables used in the empirical investigation is given in the next pages.

DEFINITIONS AND DATA SOURCES

Quarterly observations for the period 1978q1 to 1987q4. All data are seasonally unadjusted and constant price data are in 1980 prices. Standard errors are in parentheses beneath the coefficient estimates. Natural logarithmic transformation of explanatory variables are denoted by $L(\text{variable name})$.

X_t Stock of VCR in thousands. Cumulated consumer offtake (BREMA), $OS_0 + \sum_1 C_t$ where C is consumer offtake. Initial opening stock OS_0 is 43 thousand units. See text for more detailed description.

N_t Number of households in the UK in thousands (Census of Population and Social Trends). Quarterly observations from interpolation of growth rate.

TVL_t Stock of colour tv receivers. Broadcast receiving licences in force for colour tv in the UK in thousands (Monthly Digest). Adjusted for licence evasion, an average understatement of approximately 16% when cross filed with BREMA data estimates of sets in use. See next chapter for more detail.

$$XN_t = X_{t-1}/N_t$$

$$XT_t = X_{t-1}/TVL_t$$

A_t Real advertising expenditures on VCRs. Nominal advertising expenditures by both retail and rental sectors on VCRs (MEAL) in thousand pounds deflated by the average weighted press and tv media index (Advertising Association).

Q_{it} Seasonal dummy quarter i

R_t Real rate of interest. Nominal 3 month Treasury Bill yield, average discount rate expressed as a rate per annum (Economic Trends) less the rate of inflation as measured by Retail Price Index all items, RPI, (Economic Trends).

$$LR_t = \log_e(10-R)$$

- P_t** Relative average price of VCR that is average retail price index of VCRs, ARP, deflated by RPI. Where ARP is constructed using the average producer price of imported VCRs (Overseas Trade Statistics). Retail series established by multiplying producer price index by rate of VAT and retailers mark up on cost as described in the text.
- MY_t** per capita real disposable income. Real personal disposable income deflated by defacto UK home population over 15 years (Monthly Digest) in thousands.
- HPD_t** Hire purchase restrictions dummy variable. This variable took two values over the period considered, 20% before 1982q3 and zero there after. So a dummy is set equal to 1 when hire purchase minimum legal deposit required on VCR is positive, that is 1978q1 to 1982q2, otherwise set equal to 0 for 1982q3 to 1987q4 (BREMA).
- NOB** Number of observations.
- RSS** Residual Sum of Squares of the equation.
- DW** Durbin-Watson statistic for 1st order serial correlation.
- LM4** Lagrange Multiplier test for residual autocorrelation up to order 4.
- RSET** Ramsey Reset test using the square of the fitted values.
- NORM** Jarque-Bera test for normality.
- HET** Heteroscedasticity test based on regression of squared residuals on squared fitted values.
- CHOW** Chow test for stability of the regression coefficients.
- PRED** Predictive Failure Test, ie, Chow's second test of adequacy of predictions.

CHAPTER 6

AN EMPIRICAL INVESTIGATION INTO THE ROLE OF ADVERTISING IN THE DIFFUSION OF COLOUR TELEVISION RECEIVERS IN THE UK

6.1 INTRODUCTION

Attention is now turned to undertaking a similar investigation to the one in the previous chapter, but using data on the diffusion of colour television (tv) receivers in the UK. This particular product is attractive in itself, being a good example of a vertically differentiated product. This new technology has almost completely replaced the older monochrome product as can be clearly seen in diagram A6.1 in the appendix to this chapter. Moreover, previous empirical studies have looked at the television receiver (though mostly confined to the monochrome product) and it will be intriguing to make comparisons with the results obtained here and see whether the neglect of advertising in these earlier television studies, has been a major omission.

On practical grounds, estimation of a diffusion model for this product also has a potential advantage in terms of data quality and availability. A longer time series exists (almost double the observations) as the product was first commercially introduced into the UK in 1967. Furthermore, the raw data represents the number of colour TV licences in force (with a suitable adjustment for licence evasion) and this series will more accurately reflect acquisition of the first colour tv set. Consequently, the problems of multiple and replacement purchases are avoided. Of course, the data will not be completely immune from problems and a full description of the variables employed and data series is given in Appendix A6 at the end of this chapter.

6.2 ESTIMATION OF THE STRUCTURAL DEMAND DIFFUSION EQUATION

The estimating procedure will be identical to that adopted in the previous chapter. Accordingly, initial estimation will begin with the epidemic structural demand diffusion equation as follows:-

$$\frac{TVL_t - TVL_{t-1}}{H - TVL_{t-1}} = \alpha + \frac{\beta \cdot TVL_{t-1}}{H} + \sum_i \chi_i \cdot q_{it} + u_t \quad 6.0$$

where $\beta > 0$ $\chi_i < 0$

TVL_t = Stock of colour tv receivers in time t

q_{it} = Seasonal dummy variable in time t, $i = 3$

H = Potential population

α = External channel of information

β = Internal channel of information coefficient (Word of Mouth)

u_t = Error term in time t.

(A full description of the data and variables used is given in Appendix A6 at the end of this chapter)

6.2.1 Potential Population

This equation explains the proportion of non owners who become owners of a colour TV set in the time interval t-1 to t. From the literature survey in Chapter 2, it was clear that different approaches to the potential population parameter H have been used in the empirical work. Some studies have taken H as constant and its magnitude estimated from the data (eg. Horsky and Simon 1983), other writers have used an appropriate demographic variable, recognising that when using a long time series, this will obviously change over time (eg. Simon and Sebastian 1987) and others, mainly in the economics field, have explained H in terms of relevant economic variables (eg. Bain 1962, and similarly Chow 1967 and Williams 1972).

The method adopted here, as in Chapter 5, is to maintain the saturation concept but replace H with a relevant demographic variable H_t . Although the number of households in the UK (H_t) seems appropriate, it is necessary to recognise that colour transmission availability was restricted in the early period. This is likely to be an

important dampening factor on the colour TV acquisition decision. There is little point in purchasing the new technology if colour transmission facilities are not available in the area.¹ Of course, consumer's expectations may lead to purchases ahead of the introduction of the transmission service, but this lead effect is unlikely to be of any significant duration. There was a gradual spread of this service for both BBC and ITV over the period. So the number of households in the UK was adjusted to take account of this factor (AH_t). In addition, colour service was only available on BBC2 from its inception in 1967 until November 1969, when transmission also commenced on BBC1 and ITV. A dummy variable was established to take account of this extra restriction.

6.2.2 Estimation; The Basic Model

Estimation of the simple epidemic model, in which the only source of information flow is social contact between existing owners in the population, is based on the following model (results shown in Table 6.A);

$$TDP_t = \alpha + \beta \cdot OWN_t + \sum_i \chi_i \cdot q_{it} + \epsilon \cdot BBC2 + u_t \quad 6.1$$

where $\beta > 0$ $\epsilon < 0$ $\chi_i < 0$

$$TDP_t = \frac{TVL_t - TVL_{t-1}}{AH_t - TVL_{t-1}}$$

$$OWN_t = \frac{TVL_{t-1}}{AH_t}$$

BBC2 = dummy variable, takes a value 1 when colour transmission on BBC 2 channel only

β = Internal channel of information coefficient (Word of Mouth).

q_{it} = Seasonal dummy variable in time t , $i = 3$

¹ This constraint on the acquisition decision will be of most significance during the early years as by the beginning of 1973, approximately 90% of UK households could receive colour transmission on both BBC1 and ITV channels.

u_t = Error term in time t .

The explanatory variable OWN_t shows the number of existing owners in the potential population. This variable has the expected positive coefficient. Actually, by using adjusted households in the denominator, an assumption is being made that the current owners only come into contact with non-owners belonging to the potential population for which colour service is available, ie. AH_t . Since the extension of the transmission service was introduced on a regional basis and individuals will generally come into contact with people in their immediate locality, this may not be an unreasonable assumption.²

The BBC2 dummy variable, indicating restricted access to the colour service, has the expected deflationary effect on the dependent variable. The seasonal pattern of the raw data indicated that quarter 4 was most important, probably reflecting the effect of Christmas holiday viewing. The remaining seasonal dummies $q1$, $q2$, and $q3$ are included in the model and have their expected negative coefficients. Although a LM test for serial correlation up to order 4 accepts the null hypothesis of no autocorrelation, the failure of the Reset, Normality and Heteroscedasticity diagnostic tests suggest that the simple model is mis-specified.

6.2.2.1 Social Contact/Internal Information Parameter β

Before extending the model to include advertising, it is appropriate to consider previous studies which have investigated the diffusion of TV receivers. There are a few studies from the management literature which are very similar to the simple model structure given in equation 6.1 above. Bass (1969), using annual data for monochrome TVs in the USA, found β to be 0.2511. Nevers (1972), using annual data for colour TV sets in the USA, obtained a value of 0.8369 for the social contact coefficient β . These studies used very few observations (16 and 7 respectively) to obtain the structural

2. In any case, using unadjusted households in this explanatory variable, ie. TVL_{t-1}/H_t , made very little difference to the estimated model.

TABLE 6.A

Ordinary Least Squares Estimation
of the Epidemic Model.
Dependent variable is $(TVL_t - TVL_{t-1})/AH_t - TVL_{t-1}$

	MODEL 6.1	MODEL 6.1.1A	MODEL 6.1.1B
CONS	0.0357 (0.8716e-02) **	0.0232 (0.0136) *	0.0208 (0.0145)
OWN _t	0.0484 (0.0104) **	0.0401 (0.0125) **	0.0231 (0.0202)
BBC2	-0.0167 (0.0118)	-0.0176 (0.0118)	-0.0180 (0.0135)
q _{1t}	-0.1313e-02 (0.8632e-02)	0.9094e-02 (0.0123)	-0.0250 (0.0134) *
q _{2t}	-0.0283 (0.8487e-02) **	-0.0199 (0.0110) *	-0.0268 (0.0128) *
q _{3t}	-0.0260 (0.8485e-02) **	-0.0151 (0.0124)	0.6754e-02 (0.0134)
λ _t		0.3558e-05 (0.2992e-05)	0.3500e-05 (0.3222e-05)
λ _{t-1}			0.1240e-04 (0.2850e-05) **
λ _{t-2}			0.1156e-05 (0.2763e-05)
λ _{t-3}			-0.6130e-05 (0.2951e-05) *
λ _{t-4}			0.1525e-06 (0.3320e-05)
NOB	71	71	68
RSS	0.0421	0.0412	0.0287
DW	1.7372	1.8284	1.8264
AR ²	0.4476	0.4511	0.5585
LM4	Accept	Accept	Accept
RSET	Reject	Reject	Reject
NORM	Reject	Reject	Accept
HET	Reject	Reject	Reject

Standard errors in parentheses.

*, ** denotes significance at 5% and 1% respectively.

parameters from the OLS estimation. No diagnostic tests were performed. Later, Bass (1980) re-estimated the demand diffusion equations for both colour and monochrome sets in the USA, after incorporating a price effect component. He obtained estimates of 0.5298 and 0.1315 for the β coefficient respectively. Again very few observations were used and no diagnostic testing of the model undertaken. However the author informally notes that in the case of monochrome tv receivers there is some indication of mis-specification because the elasticity of demand parameter is undefined. Although referring to a different country, the size of the β coefficient in equation 6.1 when adjusted to take account of the different observation intervals, is approximately 0.16 and would seem closer to that found by Bass in his earlier work (but of course, this referred to the monochrome product).

However very little faith should be placed on any of these estimates as the probability of mis-specification in these other studies looks high, given the results found for model 6.1 above and the obvious variation in the estimates from models of very similar construction. Although not strictly equivalent to equation 6.1, there are two studies from the economics literature which have empirically investigated the diffusion of the monochrome tv receiver in the UK. Bain (1962) using quarterly data (the saturation parameter in his model is explained by economic variables), found the β coefficient to range between 0.15 and 0.277 for various television regions. However, the author does not have too much confidence in the parameters since the estimated growth curve did not perform well over the two extremes of the process. The stock adjustment model of Williams (1972), again is not strictly comparable to equation 6.1 above, however the estimated parameter can be transformed to give an approximate coefficient value of 0.23 on the existing ownership variable.³ The author found autocorrelation to be a problem and transformed the model accordingly. However there were strong indications that the non linear restrictions imposed *a priori*, were not accepted by the data.

3. Which of course is interpreted as an adjustment coefficient in Williams'(1972) model when there are no short term factors to affect it.

6.2.3 Advertising in the Epidemic Model; A Direct Route

The theoretical model presented in Chapter 3 and previous empirical work would suggest that allowing advertising to provide an additional and external direct source of information flow (through α in equation 6.1 above) could improve matters. As before, the exact form of $\alpha=f(A)$ must be ascertained from the data. To begin with, only current advertising is included. The results are given in Table 6.A for Model 6.1.1A in which,

$$\alpha = a_0 + a_1 \cdot A_t, \quad \text{and} \quad a_1 > 0 \quad 6.1.1A$$

Again all the variables have their expected signs. Advertising has a positive but small effect on the dependent variable. However, there is very little improvement in the diagnostic test statistics. Therefore some further experimentation with the number of lags and functional form of the α function was undertaken. The failure of the Reset test alone would suggest that some other functional form may be appropriate. However when a combination of diagnostic tests fail, these statistics are most likely indicating misspecification in general, rather than anything in particular. Using a logarithmic transformation of the current advertising variable (like H&S and S&S), did not improve matters overall. The Reset test still rejected the Null Hypothesis, as did the Normality and Heteroscedasticity test. The adjusted R^2 fell slightly compared with Model 6.1.1A and although little confidence should attach to this and the individual t statistics, on balance using advertising in levels seemed more appropriate.⁴

There are obviously still problems with the model and so additional lagged values of the advertising variable were included in the α function. A maximum of 4 quarter lags were used, for the reasons already explained in Chapter 5. The results for Model 6.1.1B are given in the table. As in the earlier estimation, the existing ownership variable OWN_t , reflecting the effectiveness of the word of mouth information flow, has a positive coefficient, although its statistical significance is much reduced. Of course,

⁴. The same conclusions were reached in all of the following specifications when the relevant logged advertising variable was substituted into the equation. On no occasion did this improve the performance of the model and so these results will not be reported.

reliance on the standard errors must be tentative unless the model meets the classical assumptions underlying the OLS estimation procedure. Compared to earlier specifications, there has been some slight improvement, with only the Reset and Heteroscedasticity test now failing to accept the null hypotheses. Bearing this in mind, of the additional lagged advertising variables included, the one quarter lag is most important, both in magnitude and statistical significance. One of the problems of including the lagged variables directly, is the possibility of multicollinearity, which would increase the variance of the estimated parameters. It is therefore advisable to test the significance of the advertising variables jointly (given the reservations regarding the trustworthiness of tests based upon the estimated variances of the coefficients). The null hypothesis that the 2nd, 3rd and 4th quarter lags are jointly insignificant from zero fell well within the acceptance region. The model was re-estimated including current and the first lag of the advertising variable only. As can be seen in Table 6.B, this revised model specification 6.1.1C still looks suspect.

Given the relative dominance of the lagged advertising variable, current advertising was dropped from the equation. Whilst all the variables in 6.1.1D have their hypothesised effect on the dependent variable and are all statistically significant at the 5% level, the failure of the diagnostic statistics other than the LM test for autocorrelation must cast doubt on this structure. There is little to choose between models 6.1.1C and 6.1.1D. Further experimentation with a longer lag distribution is probably superfluous since throughout, the autocorrelation test statistic fell well within the acceptance region. Generally in time series data, the presence of autocorrelation as indicated by the appropriate diagnostic test is not unexpected. It can be a sign of dynamic misspecification rather than true serial correlation of the error terms (Sargan 1964, Hendry & Mizon 1978). However as the epidemic based equation in model 6.1 already includes some form of dynamics, justified on theoretical grounds, acceptance of the null hypothesis of no serial correlation does not appear unreasonable.

TABLE 6.B**OLS Estimation of the Epidemic Model.****Dependent variable,**

$$\text{TDP} = (\text{TVL}_t - \text{TVL}_{t-1}) / \text{AH}_t - \text{TVL}_{t-1}$$

	MODEL 6.1.1C	MODEL 6.1.1D
CONS	0.0122 (0.0123)	0.0322 (0.7954e-02) **
OWN_t	0.7618e-02 (0.0134)	0.0230 (0.0115) *
BBC2	-0.0259 (0.0106) **	-0.0239 (0.0108) *
q_{1t}	-0.0201 (0.0128)	-0.0335 (0.0114) **
q_{2t}	-0.0173 (0.9816e-02) *	-0.0304 (0.7714e-02) **
q_{3t}	-0.0167 (0.0110)	-0.0332 (0.7914e-02) **
A_t	0.5604e-05 (0.2696e-05) *	
A_{t-1}	0.1150e-04 (0.2687e-05) **	0.1050e-04 (0.2712e-05) **
NOB	71	71
RSS	0.0319	0.0341
DW	1.8760	1.9512
AR²	0.5682	0.5458
LM4	Accept	Accept
RSET	Reject	Reject
NORM	Reject	Reject
HET	Reject	Reject

Standard errors in parentheses.

*, ** denotes significance at 5% and 1% respectively.

6.2.4 Simultaneous Equation Bias

As pointed out in the previous chapter, the possibility of simultaneous equation bias needs to be addressed. In chapters 3 and 4 attention was given to advertising as an endogenous variable, noting that the demand diffusion equation will then form part of a simultaneous system. Consequently, if simultaneous equation bias in the OLS estimates is to be avoided, the derived advertising appropriations equations will need to be incorporated into the estimation procedure.

As already mentioned in the previous empirical chapter, the fact that price may also be a choice variable is still being ignored. However there may be some justification in assuming that an oligopolist would prefer to engage in advertising as opposed to price competition. Additionally, in the case of VCRs it was argued that the supply side could be considered exogenous due to the relative importance of imports. For colour tv receivers this could be a more tenuous position. It is certainly true that during the early 1970's UK producers were unable to keep pace with the boom in demand due to limited production facilities. As a consequence, imports increased dramatically, accounting for approximately one quarter of all sales in the UK market in 1973. The outcome was an agreement with Japanese manufacturers to restrict exports to the UK market. It may therefore be just as appropriate to consider the endogeneity of the price variable for this particular product. Despite this, the following estimation will still concentrate upon advertising as the main decision variable.

Referring back to chapter 3, it is clear from the first order conditions for profit maximisation that the industry advertising decision equation can be summarised as follows,

$$A_t = f(\text{PCM}_t, \text{PCM}_{t+1}, R_t, AP_t, S_t, n_t) \quad 3.22$$

where

PCM_t = Industry price cost margin in period t .

PCM_{t+1} = Industry price cost margin in $t+1$.⁵

R_t = The time discount rate.

AP_t = The average retail price of the product.

n_t = The number of suppliers of the product.

$S_t = TVL_t - TVL_{t-1}$, the number of new acquirers of the product as described in the demand diffusion equation.

Using the demand diffusion equation 6.1.1C, the system is as follows

$$S_t = f(A_t, A_{t-1}, TVL_{t-1}, AH_t) \quad 6.1.1C$$

$$A_t = f(PCM_t, PCM_{t+1}, R_t, AP_t, S_t, n_t) \quad 3.22$$

Both the advertising decision equation and demand diffusion equation are over identified. Therefore Two Stage Least Squares (TSLS) estimation will be applied to the demand diffusion equation 6.1.1C. Most of the identifying restrictions on the demand equation do not look unreasonable, except for the exclusion of the price and interest rate variables. However, even if these variables were incorporated into the demand diffusion model, the price cost margin variables and number of producers would ensure the identification of the demand diffusion equation. Unfortunately, the advertising decision equation looks more suspect. It is quite feasible that previous advertising (A_{t-1}) and the existing stock of owners could enter into the equation, in which case, the advertising appropriations equation would not be identified. Estimation would then be nonsense without additional extraneous information. Still, the focus of attention in this chapter is the empirical investigation of the demand diffusion equation and the need to overcome

5. Strictly, this should be expectations of the second period price cost margin. A popular approach in the econometric literature has been to assume adaptive expectations behaviour in which case the lagged value of PCM would appear in the equation. The rational expectations hypothesis criticised such naive behaviour. In the following estimation, expectations of PCM is simply replaced by its one quarter lead value since the variable is required as an instrument. If the structural equation 3.22 was being estimated separately, more consideration would need to be given to the appropriate expectations behaviour of producers.

any potential simultaneous equation bias that may be present in the OLS estimated parameters. Estimation of the structural advertising appropriations equation itself, will not be undertaken. Therefore the plausibility of the identifying restrictions do not need to be considered further.

The TSLS estimates for model 6.1.1C are given in Table 6.C. The variables have their expected coefficient signs except for current advertising. However the null hypothesis that this variable is not significantly different to zero falls well within the acceptance region. In comparison to the OLS parameter estimates, the magnitudes are in fact very similar to model 6.1.1D, which only contains the lagged advertising variable. The exclusion of current advertising from the specification means the OLS estimates in model 6.1.1D will not suffer from simultaneous equation bias because the demand diffusion equation will form part of a recursive system.

Using the estimated parameters in model 6.1.1D, the direct effectiveness of lagged advertising on the number of new acquirers of a colour tv receiver in the current period can be evaluated. In 1968q2, an increase in real advertising messages by £1000 in the previous quarter, will result in an extra 92 new acquirers of a colour tv receiver. At the end of the sample period in 1985q4, the same increase in real advertising messages in the previous quarter will stimulate 15 new acquirers of the product.⁶ This diminishing effectiveness overtime is a particular feature of the epidemic model as explained in chapters 3 and 5. Unfortunately, the diagnostic tests for model 6.1.1D indicated problems still remained in the specification. Of course this direct route is not the only way in which advertising can enter into the epidemic framework. So the study will now proceed to the alternative epidemic model specification where the β coefficient of the existing ownership variable in equation 6.1 above, is a function of advertising expenditures.

6. Evaluated at actual values of the variables in the respective periods.

TABLE 6.C**OLS and TSLS Estimation of the Epidemic Model.****Dependent variable,**

$$\text{TDP} = (\text{TVL}_t - \text{TVL}_{t-1}) / \text{AH}_t - \text{TVL}_{t-1}$$

MODEL 6.1.1C

	OLS Estimates	TSLS Estimates^s
CONS	0.0122 (0.0123)	0.0403 (0.0335)
OWN_t	0.7618e-02 (0.0134)	0.0292 (0.0277)
BBC2	-0.0259 (0.0106) **	-0.0231 (0.0177) *
q_{1t}	-0.0201 (0.0128)	-0.0389 (0.0248)
q_{2t}	-0.0173 (0.9816e-02) *	-0.0358 (0.0228)
q_{3t}	-0.0167 (0.0110)	-0.0398 (0.0280)
A_t	0.5604e-05 (0.2696e-05) *	-0.2272e-05 (0.9122e-05)
A_{t-1}	0.1150e-04 (0.2687e-05) **	0.1010e-04 (0.3245e-05) **
NOB	71	71
RSS	0.0319	0.0362
DW	1.8760	1.9794
AR²	0.5682	0.5098
LM4	Accept	Accept+
RSET	Reject	Accept+
NORM	Reject	Reject+
HET	Reject	Accept+

Standard errors in parentheses.

*, ** denotes significance at 5% and 1% respectively.

^s List of instruments PCM_t , PCM_{t+1} , R_t , AP_t , OWN_t , A_{t-1} , dummies and constant term. Sargan's Test statistic (1964) accepts the null hypothesis that the equation is correctly specified and the instruments are valid.

+ Diagnostic tests applicable to TSLS estimation, using instrumental variable fitted values and residuals as appropriate.

6.2.5 Advertising in the Epidemic Model; An Indirect Route

In this alternative specification, advertising has an indirect effect on the diffusion process. This may occur if consumers perceive bias in the information transmitted by producers of the new durable. Further impartial information will be required before potential consumers are convinced of the accuracy of the advertiser's claims. The alternative and independent source of information will be an existing owner and consequently this channel of communication will be relatively more effective (Porter 1976). This line of reasoning would seem particularly appropriate for new consumer durables. The inherent characteristics of such products make purchase an uncertain and potentially costly exercise, especially since there may be questions over the technical reliability that often accompany new and relatively complex products. Of course there are some consumer durables for which an established rental sector exists (colour tv and VCR being examples) and this facility would tend to mitigate these negative factors. On this same point, the existence of a rental sector may help overcome the problem of consumer expectations of future technological advance slowing the diffusion process.

To begin with, the social contact coefficient β in equation 6.1, is assumed to depend linearly on current advertising. So that

$$\beta = b_0 + b_1.A_t$$

where $b_0 > 0$ and $b_1 > 0$

6.1.2

The results for model 6.1.2 are given in table 6.D. All the economic variables have their expected sign. However the statistical significance of b_1 looks dubious. Compared to the model in which advertising enters directly, there seems little improvement, as once again all the diagnostic tests other than the LM statistic fail. Also the adjusted R^2 , which was relatively low in the earlier models, is now even lower. Adding the first quarter lag of advertising into the model (6.1.2A) did improve matters slightly, increasing the adjusted R^2 from 0.447 to 0.591. Both the LM and Reset test statistics are accepted yet the failure of the Heteroscedasticity test still gives some reason to doubt the specification. However, the standard errors (SE) were adjusted, as suggested

TABLE 6.D**OLS Estimation of the Epidemic Model.**

$$\text{Dependent variable,} \\ \text{TDP} = (\text{TVL}_t - \text{TVL}_{t-1}) / \text{AH}_t - \text{TVL}_{t-1}$$

	MODEL 6.1.2	MODEL 6.1.2A	MODEL 6.1.2B
CONS	0.0321 (0.9467e-02) **	0.0431 (W0.8099e-02) **	0.0489 (0.8382e-02) **
OWN_t	0.0372 (0.0156) *	-0.0281 (W0.0259)	0.3619e-03 (0.0141)
BBC2	-0.0173 (0.0118)	-0.0261 (W0.5848e-02) **	-0.0237 (0.0106) *
q_{1t}	0.4981e-02 (0.0108)	-0.0173 (W0.8792e-02) *	-0.0272 (0.9853e-02) **
q_{2t}	-0.0233 (0.9957e-02) *	-0.0191 (W0.7727e-02) *	-0.3000 (0.7577e-02) **
q_{3t}	-0.0193 (0.0109) *	-0.0186 (W0.9028e-02) *	-0.0323 (0.7712e-02) **
AX_t	0.3036e-05 (0.3145e-05)	0.6735e-05 (W0.5079e-05)	
AX_{1t}		0.1370e-04 (W0.3535e-05) **	0.1190e-04 (0.2816e-02) **
NOB	71	71	71
RSS	0.0415	0.0302	0.0330
DW	1.8051	1.8338	1.9397
AR²	0.4470	0.5912	0.5608
LM4	Accept	Accept	Accept
RSET	Reject	Accept	Reject
NORM	Reject	Reject	Reject
HET	Reject	Reject	Accept

Standard errors in parentheses, W=White adjusted.
 *, ** denotes significance at 5% and 1% respectively.

by White (1980), in order to be consistent in the presence of a non constant variance of the disturbance terms. The White adjusted SE on the lagged advertising variable coefficient increased but still remained statistically significant. The current advertising variable also had a positive coefficient but was no longer significant. However a joint test of significance using the White adjusted errors, shows that the two advertising variables are significantly different to zero at the 5% and 1% level. The estimated coefficient on the existing ownership variable is unusually negative, although statistically insignificant. This is some what surprising as it suggests the existing ownership variable has no effect in the absence of advertising.

Model 6.1.2 was re-estimated using TSLS procedures and the information from the advertising appropriations equation 3.22. The results are shown in Table 6.E. The existing ownership variable had a positive but statistically insignificant coefficient. The current advertising variable had a negative but insignificant coefficient, whilst the lagged advertising variable had a positive effect and although reduced, it was still significant at the 5% level. The results would suggest that dropping current advertising from the equation and re-estimating using OLS procedures would be appropriate. The results for model 6.1.2B are displayed in table 6.D. The benefit of this step was ambiguous. Although the Heteroscedasticity test is just accepted, the Reset test now fails. The magnitude of the coefficient on the existing ownership variable seems very low at 0.0036 but in any case is statistically insignificant. However the lagged advertising variable has a positive and statistically significant coefficient at both the 5% and 1% levels. Its magnitude of 0.119e-04 is very similar to the TSLS and the OLS estimate in model 6.1.2A.

Establishing a combined model in which advertising enters through the social contact coefficient β and directly as an external channel of information α , did not produce any better results. When both current and lagged advertising were included in the combined model, none of the economic variables were significant and some had the wrong signs. This confirms the experience of S & S. These authors also obtained several

TABLE 6.E**OLS and TSLS Estimation of the Epidemic Model.**

$$\text{Dependent variable,} \\ \text{TDP} = (\text{TVL}_t - \text{TVL}_{t-1}) / \text{AH}_t - \text{TVL}_{t-1}$$

MODEL 6.1.2A

	OLS Estimates	TSLS Estimates^{\$}
CONS	0.0431 (W0.8099e-02) **	0.0568 (0.0137) **
OWN_t	-0.0281 (W0.0259)	0.0464 (0.0536)
BBC2	-0.0261 (W0.5848e-02) **	-0.0204 (0.0132)
q_{1t}	-0.0173 (W0.8792e-02) *	-0.0407 (0.0198) *
q_{2t}	-0.0191 (W0.7727e-02) *	-0.0447 (0.0196) *
q_{3t}	-0.0186 (W0.9028e-02) *	-0.0507 (0.0238) *
AX_t	0.6735e-05 (W0.5079e-05)	-0.9085e-05 (0.1080e-04)
AX_{1t}	0.1370e-04 (W0.3535e-05) **	0.9395e-05 (0..4474e-05) *
NOB	71	71
RSS	0.0302	0.0454
DW	1.8338	2.0468
AR²	0.5912	0.3854
LM4	Accept	Accept+
RSET	Accept	Accept+
NORM	Reject	Reject+
HET	Reject	Accept+

Standard errors in parentheses, W=White adjusted.

*, ** denotes significance at 5% and 1% respectively.

^{\$} List of instruments PCM_t , PCM_{t+1} , R_t , AP_t , OWN_t , AX_{1t} , dummies and constant term. Sargan's Test statistic (1964) accepts the null hypothesis that the equation is correctly specified and the instruments are valid.

+ Diagnostic tests applicable to TSLS estimation, using instrumental variable fitted values and residuals as appropriate.

wrong parameter signs and rejected the combined model on grounds of econometric intractability. The two competing epidemic models are obviously nested within the combined model and some attempt was made to distinguish between the two on statistical grounds using an F test. Both current and the first quarter lag advertising variables were included in α and β . Deleting the advertising variables from the α route accepts that they are not significantly different to zero. Unfortunately, the same conclusions are reached in respect of the advertising variables in the β coefficient. Thus there is no clear statistical preference for either structure.

6.2.6 Preliminary Conclusions

The lack of statistical guidance on the best epidemic specification is unfortunate since the magnitude and significance of the existing ownership variable is very sensitive to the specification adopted and the econometric technique used. This would suggest that previous findings need to be treated with great caution, especially when little if any diagnostic testing has been undertaken. The role of advertising in the epidemic demand diffusion equation looks slightly more convincing. Unfortunately the data cannot distinguish whether advertising enters directly or indirectly into the equation. However the first quarter lag of advertising appears to be an important explanatory variable in the epidemic demand diffusion model for this particular product. It is also satisfying to note that the magnitude and statistical significance of this variable remained consistent throughout. Yet these preliminary conclusions must remain tentative as the statistical performance of all the models estimated indicated further improvement was necessary. Thus the epidemic model, even with advertising included is not altogether satisfactory.

6.2.7 Restricting the Sample Period

The central issue in the epidemic framework is the lack of information about the product. Such a deficiency is likely to be most acute in the early period immediately after introduction. Consequently the epidemic specification may only be reasonable for a

relatively short length of time.⁷ This may be particularly true for colour television receivers since a similar (although generally agreed inferior) product had been in existence for some time, so it is reasonable to expect that consumers had some knowledge about television sets. In contrast, the VCR was a totally new innovation and potential consumers may require a greater stock of information before acquisition. To investigate further, the sample period was broken into two periods at 1977iv. Some absorbing results emerge (only the preferred model results are given in table 6.F and G). Generally the second period samples appear to have reasonable structures as most of the diagnostic tests accepted the null hypotheses, although there are of course fewer degrees of freedom and these test statistics are asymptotic. However the explanatory power of the equations in the second period are very low (adjusted R^2 statistics around 0.4). Further, hardly any of the economic variables were statistically significant. But before too much is placed upon the second period sample it is worth remembering that by 1979 some 73% of all households had acquired their first colour tv receiver and the growth rate of the stock of first tv sets had more or less settled at a constant and very low rate. So it may be unreasonable to expect the data to explain much over this later period.

Turning to the early period, which covered the first 10 years of the diffusion process, the diagnostic tests indicate that autocorrelation was a particular problem. Ideally the structure should be investigated further to see if the reason can be found. Nonetheless, in order to obtain an indication of the estimated coefficients and statistical significance, the equations were transformed and re-estimated. Whilst the LM test statistic indicated autocorrelation up to order 4, on closer inspection, first order serial correlation looked mostly to blame, so a first order autoregressive process was assumed in the re-estimation stage. The explanatory power of the equation was much higher than the second sample with the adjusted R^2 statistics around 0.8. Again it is debatable as to the preferred route for advertising in the epidemic model. In the shorter period, current

⁷. In this case, the estimated epidemic model will be of historical interest only and ideally a general model should be able to explain the whole diffusion process, not just some segment of it.

TABLE 6.F**OLS and Maximum Likelihood Estimation of the Epidemic Model.**

Dependent variable,

$$TDP = (TVL_t - TVL_{t-1}) / AH_t - TVL_{t-1}$$

MODEL 6.1.1A

1968q1 to 1977q4[§] 1978q1 to 1985q4

CONS	0.0133 (0.9144e-02)	0.0163 (0.0753)
OWN_t	0.0444 (0.0174) **	0.0492 (0.0874)
BBC2	-0.0172 (0.9320e-02) *	
q_{1t}	-0.1381e-02 (0.5124e-02)	0.0255 (0.0322)
q_{2t}	-0.0109 (0.4971e-02) *	-0.0278 (0.0282)
q_{3t}	-0.4550e-02 (0.5018e-02)	-0.0241 (0.0342)
A_t	0.6625e-05 (0.2219e-05) **	0.3069e-05 (0.6253e-05)
NOB	39	32
RSS	0.2864e-02	0.0304
DW	1.6410	1.8164
AR²	0.8107	0.2402
LM4	Reject+	Accept
RSET	Accept	Reject
NORM	Accept	Accept
HET	Accept	Accept

$$U_t = 0.5703U_{t-1} + V_t$$

(0.1506) **

§ Re-estimated by Maximum Likelihood Estimation subject to autoregressive error specification.

+Diagnostic tests from original OLS estimation.
 Standard errors in parentheses.

*, ** denotes significance at 5% and 1% respectively.

TABLE 6.G

OLS and Maximum Likelihood Estimation of the Epidemic Model.

Dependent variable,
 $TDP = (TVL_t - TVL_{t-1}) / \Delta H_t - TVL_{t-1}$

MODEL 6.1.2A

1968q1 to 1977q4^{\$}

1978q1 to 1985q4

CONS	0.0276 (0.0112) **	0.1056 (0.0695)
OWN_t	-0.0324 (0.0354)	-0.1000 (0.0949)
BBC2	-0.8795e-02 (0.9297e-02)	
q_{1t}	-0.5693e-02 (0.3344e-02) *	-0.0387 (0.0350)
q_{2t}	-0.0102 (0.3535e-02) **	-0.0273 (0.0239)
q_{3t}	-0.4705e-02 (0.3216e-02)	-0.0335 (0.0288)
AX_t	0.1940e-04 (0.3680e-05) **	0.1740e-04 (0.5953e-05) **
AX_{1t}	0.1090e-04 (0.4726e-05) *	0.5388e-05 (0.6007e-05)
NOB	39	32
RSS	0.1966e-02	0.0226
DW	1.7173	2.1919
AR²	0.8656	0.4124
LM4	Reject+	Accept
RSET	Accept	Accept
NORM	Accept	Accept
HET	Accept	Accept

$$U_t = 0.7764U_{t-1} + V_t$$

(0.1385) **

^{\$} Re-estimated by Maximum Likelihood Estimation subject to autoregressive error specification.

+Diagnostic tests from original OLS estimation.
Standard errors in parentheses.

*, ** denotes significance at 5% and 1% respectively.

advertising rather than lagged advertising appears to be more important, such transience is disquieting.

The findings of a TSLS estimation procedure (subject to a first and fourth order auto regressive error specification) were disappointing with none of the variables being statistically significant and are not reported. Of course the advantages of the TSLS procedure can be at the expense of increased variance in the estimated parameters. But given the volatility of both the parameter estimates and statistical significance of the existing ownership and advertising variables in this earlier period, coupled with the autocorrelation problem, some doubt must be cast on the adequacy of the epidemic framework for this product.

6.2.8 Preliminary Conclusions Revisited

When using the whole sample period, the lagged advertising variable appeared to give promising results. The statistical significance and magnitude of the coefficient on this variable was consistent throughout. However the data was unable to distinguish whether advertising entered directly through the internal channel of information β or provided a direct channel of information α . This failing was serious because of the sensitivity of the coefficient of the existing ownership variable to the alternative specification chosen. Further ambiguities arose when the sample size was restricted to the first ten years of the diffusion process. Ideally the model should explain the whole period rather than a segment of it but given the relative lack of variation in the growth rate in later years, this may not be feasible for this particular product. In the shorter period, current advertising emerged as the more important of the advertising variables yet its statistical performance was more debatable, especially when the possibility of simultaneous equation bias was corrected for.

It is clear that the epidemic model produced some intriguing results, especially for the complete sample. However its reliability as an adequate framework to describe the demand diffusion process is debatable, particularly given the instability of the

estimated parameters over the early period when the epidemic model should have been most appropriate. Perhaps this conclusion is not too surprising as even with the inclusion of advertising, the model is a relatively simple specification. Many variables are missing, which from an economic point of view, could be very influential on the diffusion process. In order to see if this is the case, attention is now turned to the alternative probit based demand diffusion equation presented in chapter 4.

6.3 ESTIMATION OF THE PROBIT STRUCTURAL DEMAND DIFFUSION EQUATION

6.3.1 Estimation; the Static Equilibrium Model

Using the information contained in chapter 4, the basic estimating equation is as follows;

$$\log (TVL_t / AH_t - TVL_t) = - (Z_t^*) + \psi \cdot BBC2_t + \sum_i \theta_i \cdot q_{it} + u_t$$

and

$$Z_t^* = f(A_t, P_t, R_t) \quad 6.3$$

where

TVL_t = Stock of colour tv receivers in time t

A_t = Total number of advertising messages in time t

P_t = Relative retail price of colour tv receiver in time t

R_t = Real rate of interest in time t

AH_t = Number of households in the UK, adjusted for colour service transmission.

$BBC2$ = dummy variable, takes a value 1 when colour transmission on BBC 2 channel only

q_{it} = Seasonal dummy variable in time t, $i=3$

(A full description of all the variables and data is given in the appendix at the end of this chapter)

The results for this simple specification are not recorded but not surprisingly, all of the diagnostic tests calculated fell well within the reject region, indicating strongly that model 6.3 was mis-specified, so little attention should be given to the individual coefficients estimated. However, of the interesting variables, only the price term and BBC2 dummy had their expected coefficient signs. The large adjusted R^2 should not be given too much emphasis as this is quite common with time series data.

In the last chapter, additional economic variables were included in an *ad hoc* fashion to the basic estimating equation in an attempt to improve the specification. This is obviously also required here. Per capita income (MY) is included in the above equation as the income constraint will be just as important to the colour television acquisition decision. Likewise, credit restrictions are also bound to be relevant for this particular product. In the VCR model, the relevant variable used was a dummy to reflect the minimum legal proportion required as a deposit. As the time series for the colour tv is longer, this proportion varied far more and the deposit variable DPST is included directly into equation, thus

$$Y_t = \xi + \pi.P_t + \gamma.A_t + \rho.R_t + \mu.MY_t + \eta.DPST_t + \psi.BBC2_t + \sum_i \theta_i q_{it} + u_t \quad 6.3A$$

where

$$Y_t = \log (TVL_t / AH_t - TVL_t)$$

$$\pi < 0 \quad \gamma > 0 \quad \rho < 0 \quad \mu > 0 \quad \eta < 0 \quad \psi < 0 \quad \theta_i < 0$$

The results for model 6.3A are given in Table 6.H. There is no improvement in the interpretation of the diagnostic test statistics, with only the Reset test accepting the null hypothesis. The additional variables, MY and DPST do have their respective positive and negative coefficients but the interest rate variable and advertising variable still behave perversely, having incorrect coefficient signs.

TABLE 6.H**OLS Estimation of the Probit Model.****Dependent variable, $Y_t = \log(TVL_t / AH_t - TVL_t)$**

	MODEL 6.3A	MODEL 6.3B	MODEL 6.3C
CONS	4.0290 (1.3787) **	3.2916 (1.1164) **	3.8140 (1.1317) **
P_t	-0.0163 (0.8377E-03) **	-0.0158 (0.6863e-03) **	-0.0163 (0.7296e-03) **
A_t	-0.6300e-04 (0.3140e-04) *		-0.4830e-04 (0.2630e-04) *
A_{t-1}		-0.2470e-04 (0.2590e-04)	-0.3520e-04 (0.2610e-04)
R_t	0.2158e-02 (0.7440E-02)	0.9417e-03 (0.6090e-02)	0.2743e-02 (0.6055e-02)
MY_t	0.6903e-03 (0.1368e-02)	0.1107e-02 (0.1126e-02)	0.9188e-03 (0.1109e-02)
DPST_t	-0.1527 (0.3030)	-0.2766 (0.2498)	-0.2036 (0.2483)
BBC2	-0.5926 (0.1485) **	-0.4247 (0.1280) **	-0.3930 (0.1268) **
q_{1t}	-0.2404 (0.1311) *	0.1036 (0.1117)	-0.9015e-02 (0.1256)
q_{2t}	-0.2548 (0.1177) *	-0.0933 (0.0745)	-0.2080 (0.0962) *
q_{3t}	-0.2764 (0.1313) *	-0.0646 (0.0759)	-0.2053 (0.1069) *
NOB	72	71	71
RSS	4.2993	2.8751	2.7222
DW	0.5101	0.4884	0.4790
AR²	0.9864	0.9900	0.9904
LM4	Reject	Reject	Reject
RSET	Accept	Accept	Accept
NORM	Reject	Accept	Accept
HET	Reject	Reject	Reject

Standard errors in parentheses.

*, ** denotes significance at 5% and 1% respectively.

The precise functional nature in which the economic variables enter the Z^* function was not given *a priori* and so needs investigating. The equation was re-estimated using logarithmic transformation of the explanatory variables. Unfortunately this did not give any better results. Some diagnostic test statistics improved (eg. the Normality test accepts the null hypothesis) but at the expense of the failure of others (eg. the Reset test now rejects the null hypothesis). Also the results are disappointing in economic terms, advertising still has a negative coefficient and although the interest rate variable is now negative as expected, the hire purchase deposit variable did not have its correct coefficient sign. The results are therefore inconclusive between these two alternative specifications.

6.3.2 Estimation; A Dynamic Model

Of course, the probit model derived in chapter 4 is a static equilibrium concept. Consequently it is not surprising to find the diagnostic tests (DW and LM4) indicating autocorrelation. Dynamic mis-specification is likely to be the cause. Further investigation must focus on this aspect first. It may be that once the correct dynamics are discovered the other problems (as indicated by the remaining diagnostic tests) disappear since they may merely be symptoms of the same root cause.

Of all the explanatory variables, advertising is the prime candidate for including lagged values as was suggested in the theoretical chapters. Given the earlier estimation of the epidemic based model, the first quarter lag was substituted for current advertising in the equation. There is some slight improvement compared to model 6.3A but in economic terms the negative coefficient on the lagged advertising variable and the positive one on the rate of interest is still disquieting. The LM4 and DW statistic seem to suggest that first order autocorrelation is the main problem in the specification. If serial correlated disturbance terms exist in the model, the estimated parameters will be unbiased and consistent but not minimum variance. Therefore the statistical significance of the coefficients should be treated with caution.

These simple dynamics are obviously not sufficient. The importance of the first quarter lag may reflect the fact that a peak effect in a longer lag structure is required, so an Almon lag distribution on the advertising variable was investigated. Both a second and third order polynomial was tried, along with various lag lengths up to a maximum of 8 quarters. Unfortunately this avenue of research did not prove fruitful and the results are therefore not reported. Throughout, the autocorrelation test statistics strongly indicated serial correlation (mostly of the first order) was present. Since there were also suggestions of a non constant variance and some of the advertising coefficients behaved perversely, the overall conclusion must be that the model specification is incorrect. Therefore simply transforming the equation to remove the serial correlation would not be appropriate. Instead the specification of the model must be reappraised.

6.3.2.1 Distributed Lags vs Partial Adjustment

The disappointing results could have emerged because the form of the lag distribution was mis-specified. An infinitely geometrically declining lag structure on the advertising variable alone was investigated, but this did not prove successful. However it may be more relevant to include dynamic terms for the other economic variables too. If they all have a common rate of decay then estimating equation 6.3D in Table 6.I is produced. Actually the same estimation equation would result from assuming a partial adjustment behavioural hypothesis on the equilibrium relationship described in equation 6.3 and this type of behaviour could be just as relevant. Although equation 6.3 describes the equilibrium stock of colour tv as the economic variables change over time, there may not be immediate adjustment, perhaps because individuals already own a recently purchased monochrome set. It could be some time before the existing owner is prepared to discard the mono receiver in favour of the new technology. For an individual who does not currently own a tv set, adjustment would be immediate once the ownership condition (equation 4.3 in Chapter 4) holds, but as noted in the appendix to this chapter, by 1967 some 86% of UK households already had acquired a monochrome set.

TABLE 6.I

OLS Estimation of the Probit Model.
 Dependent variable, $Y_t = \log(TVL_t / AH_t - TVL_t)$

	MODEL 6.3D	MODEL 6.3E
CONS	0.5084 (0.2409) *	0.3379 (W0.2177)
P_t	-0.1830e-02 (0.3971e-03) **	-0.1422e-02 (W0.3815e-03) **
A_t	-0.6336e-05 (0.5289e-05)	
A_{t-1}		0.1310e-04 (W0.5422e-05) **
R_t	0.3710e-03 (0.1222e-02)	-0.8570e-04 (W0.1164e-02)
MY_t	0.1864e-03 (0.2259e-03)	0.2100e-03 (W0.1924e-03)
$DPST_t$	-0.1846 (0.0499) **	-0.2048 (W0.0417) **
BBC2	0.0273 (0.0278)	0.0193 (W0.0415)
q_{1t}	-0.0323 (0.0222)	-0.0541 (W0.0223) **
q_{2t}	-0.0830 (0.0197) **	-0.0696 (W0.0146) **
q_{3t}	-0.0779 (0.0220) **	-0.0671 (W0.0136) **
Y_{t-1}	0.8554 (0.0225) **	0.8705 (W0.0215) **
NOB	71	71
RSS	0.1122	0.1032
D-h	2.1459	1.7339
AR^2	0.9996	0.9996
LM4	Reject	Accept
RSET	Accept	Accept
NORM	Accept	Accept
HET	Reject	Reject

Standard errors in parentheses. W = White adjusted.
 *, ** denotes significance at 5% and 1% respectively.

The overall effect of current stocks of monochrome tv receivers on adjustment to the new equilibrium, will depend partially upon the age distribution of the monochrome sets. The older the average age of existing monochrome sets, the more likely it is that individuals will be prepared to undertake premature scrapping, thus reducing the constraining factor on the acquisition of the new technology. The age distribution over the sample period was not known, but it is likely to decrease over time once the new product was introduced. Consequently, the rate of adjustment to the desired equilibrium position given in equation 6.3 could change over time. However in the estimation model, the adjustment will be assumed constant for simplicity and 6.3D results.⁸

Some attempt was made to include the stock of monochrome sets in the equation directly without recourse to the partial adjustment hypothesis but the resulting equation did not perform too well. Incidentally, the partial adjustment should really apply to the colour tv variable equation rather than the transformed equation 6.3. However if this was followed rigorously, then a complex non linear model would result and it is unlikely that any better results would emerge. Consequently the estimated adjustment parameter in model 6.3D is related to the true adjustment parameter but is only an approximation.

In terms of the diagnostic tests for model 6.3D, only the heteroscedasticity statistic is rejected. One reason for the probable non constant variance could be a difference over time in the accuracy of the advertising variable. As explained in the appendix A6, by necessity the time series for this variable included expenditure on both colour and monochrome tv receivers. The resulting problems are likely to be most severe in the early period when the volume of advertising on the existing and established monochrome product, would tend to dominate. So in the beginning, the true level of advertising expenditure on colour tvs will be lower than measured. Later on, the data is

8. Since $Y_t - Y_{t-1} = \lambda(Y_t^* - Y_{t-1})$, where Y_t^* will be given by equation 6.3 and λ is the rate of adjustment parameter.

more likely to reflect the variable required. Unfortunately, nothing could be done to improve the accuracy of the advertising data so White adjusted standard errors are given, since these estimates will be consistent in the presence of heteroscedasticity.

Although the LM test showed no autocorrelation up to order 4, Durbin's h statistic (which is appropriate when one of the explanatory variables is a lagged dependent variable), conflicts with the LM statistic and it is surprising that the LM statistic did not pick this up. Knowing which gives the truer picture is very important since the OLS estimates will be biased and inconsistent if autocorrelation is a problem. However a plot of the CUSUM and CUSUMSQ recursive residuals does not give any particular reason to doubt the specification.

The price and hire purchase variable are negative and statistically significant at both the 5 and 1% levels. The income variable and BBC2 dummy variable have their correct signs but are not statistically significant. The advertising variable has an unexpected negative coefficient and although it is statistically insignificant, this is perplexing. The rate of interest variable also has the wrong sign from an economic point of view but once again it is statistically insignificant. The lagged dependent variable which has resulted from the Koyck or partial adjustment transformation process is positive and strongly significant. In fact, as in the last chapter, this variable dominates the equation. The magnitude of its coefficient implies a rate of decay of 0.1446, translated in partial adjustment terms, this means that it will take about three and a half years to accomplish 90% of the desired adjustment to the new equilibrium position. Given the nature of the product under investigation, this may not be too unreasonable. Of course this variable may be relevant in its own right, picking up a bandwagon or word of mouth effect.

Not too much attention should be given to these results because the possibility of first order autocorrelation should be further investigated. Given earlier results, the first quarter lag of advertising was used instead of current advertising (there will still be an

infinitely declining lag structure on this variable, but current advertising is no longer important in the current period). The results for model 6.3E in Table 6.I are far more encouraging. From an economic viewpoint, all the coefficients on the variables other than the BBC2 dummy are correct. Both the Reset and Normality test are accepted and LM4 also accepts the null hypothesis of no autocorrelation up to order 4. Durbin's h statistic is ambiguous, accepting the null hypothesis at the 1% level but not at the 5% level. A LM test up to order 1 was therefore calculated. The LM test statistic fell well within the acceptance region as did the individual t statistic on the first quarter lag of the residual. On balance, it is probably safe to conclude that this specification is free from serial correlation. This is encouraging as the estimated parameters can be considered unbiased and consistent.

However the variance will not be efficient as indicated by the failure of the Heteroscedasticity test. As mentioned earlier, this could be due to the changing accuracy of the advertising data over time. The SE were therefore adjusted as suggested by White. Compared to the White adjusted SE, the OLS standard errors were generally very close except for the BBC2 dummy variable. Its variance increased considerably, serving to reduce the t statistic, thus confirming its statistical insignificance. The relative price, hire purchase deposit and lagged advertising variable were all statistically significant at the 5 and 1% levels. The coefficients on the income and real rate of interest variables, although of correct economic sign, were not statistically significant. Once again, it is the lagged dependent variable which is dominating the equation, although both the price and deposit variables also appear important.

As model 6.3E looks promising, it is worth testing this structure further. A plot of CUSUM and CUSUMSQ recursive residuals did not give any particular reason to doubt the specification. A further investigation of the structural stability of the model would normally entail calculating a Chow test. However given the presence of the BBC2 dummy variable, estimation of a second sample, which is required for the test statistic, is not feasible due to singularity of the data. Simply dropping this dummy variable in the

second period only would not be appropriate for the calculation of the test statistic. There are two approaches to this problem. Firstly Chow's second test (which is also used as a predictive failure test) can still be calculated, as it avoids the need to estimate the second sample separately. A break point of 1978q4 was chosen on a number of economic grounds. In 1979 a newly elected conservative government led to changes in the taxation and social benefits policy, which in turn affected the distribution of income. The upsurge in unemployment during this period was also likely to have affected the variance of the income distribution. Furthermore, the recently introduced complementary VCR product, could have had a positive influence upon the perceived benefit of colour tv acquisition. The tv product itself changed over time and in particular the Teletext facility was incorporated into some tv models. This effectively increased the quality of the colour tv receiver.⁹ Actually this extra feature had been available prior to this date but a national teletext awareness campaign was undertaken in late 1978 leading to increased consumer knowledge on this facility. Ideally, the price variable should incorporate such quality improvements (Chow 1967 Stoneman 1976) but the basic producer price index used in the construction of this variable assumes the quality of the product is constant.¹⁰ The test statistic accepted the null hypothesis that the prediction errors were not statistically different to zero. This is surprising given the suggested reasons for a structural change after this date, unless of course these factors were of minor importance.

The second approach to the singularity problem, was to drop the BBC2 dummy variable from the full sample (and since it was statistically insignificant this may not be unreasonable) and conduct a Chow structural break test (after confirming that the differences in the two sample variances were not statistically significant, this being necessary before the Chow test is appropriate Amemiya 1989). The Chow test statistic accepted the null hypothesis of no structural break after 1978q4.

9. The data could not be disaggregated to distinguish between sets with and without teletext capabilities.

10. As the price variable performed relatively well throughout the estimation, it is unlikely that such an adjustment would be worthwhile. This proved the case when an alternative relative price variable was used which showed the relative producer price indices for colour and monochrome sets. This variable was still negative and significant but the separately included luxury goods purchase tax or VAT rate looked more important.

6.3.3 Restricting the Sample Period

Since model 6.3E does not include current advertising, there is no need to undertake TSLS estimation as the OLS estimates should be unbiased as the equation will form part of a recursive system.¹¹ However, given the results for the epidemic model, it will be interesting to take a closer look at the two samples separately. The first sample will include the BBC2 dummy variable, whereas the second one will obviously not. The results are given in table 6.J and raise some questions on the above analysis. In the second sample, the diagnostic tests all fall well within the acceptance region. The economic variables all have their correct signs but none other than the lagged dependent variable is statistically significant. Most of the explanatory power of the equation is coming from this variable. Of course as already pointed out, there is very little variation in the dependent variable over this period, so it is not surprising that the economic variables do not appear to contribute to the explanatory power of the equation.

The early period shows strong signs of mis-specification given the failure of all of the diagnostic tests other than the Reset test. Due to the presence of a lagged dependent variable coupled with autocorrelation, the RSS of the equation will be contaminated. This might explain why the Chow test accepts the structural stability of the model even though a closer inspection of the individual coefficients across the two time periods would seem to contradict this conclusion. The early period model was re-estimated subject to a first order autoregressive error process. Compared to the OLS estimates, the variables which are statistically significant and have their expected signs are once again the relative price, hire purchase deposit and lagged dependent variables. However the income variable which has its correct positive coefficient is now statistically significant at the 5% level. The advertising variable whilst being positive as expected, is not statistically significant and so no longer appears to be an important explanatory variable. One worrying feature is the wrong positive signed coefficient on the BBC2 dummy variable which is also statistically significant at the 5% level. Of course the

¹¹ Of course the possibility of the price variable being endogenous has still been ignored as explained earlier in the text.

TABLE 6.J

OLS and Maximum Likelihood Estimation
of the Probit Model.
Dependent variable, $Y_t = \log(TVL_t / AH_t - TVL_t)$

MODEL 6.3E
1968q1 to 1978q4^s 1979q1 to 1985q4

CONS	0.1286 (0.2504)	0.1599 (0.4763)
P_t	-0.9146e-03 (0.4508e-03) *	-0.3427e-03 (0.9593e-03)
A_{t-1}	0.1870e-05 (0.9954e-05)	0.1230e-04 (0.8561e-05)
R_t	0.8812e-03 (0.1109e-02)	-0.6509e-03 (0.5488e-02)
MY_t	0.3403e-03 (0.1969e-03) *	0.1027e-03 (0.6620e-03)
$DPST_t$	-0.1619 (0.0423) **	-0.2127 (0.1621)
BBC2	0.0462 (0.0207) *	
q_{1t}	-0.0339 (0.0357)	-0.0260 (0.0502)
q_{2t}	-0.0869 (0.0134) **	-0.0417 (0.0289)
q_{3t}	-0.0532 (0.0294) *	-0.0591 (0.0272) *
Y_{t-1}	0.9074 (0.0237) **	0.9290 (0.0738) **
NOB	43	28
RSS	0.0306	0.0310
D-h	2.2419+	-1.0849
AR^2	0.9996	0.9928
LM4	Reject+	Accept
PSET	Accept+	Accept
NORM	Reject+	Accept
HET	Reject+	Accept

$$U_t = -0.6019U_{t-3} + V_t$$

(0.1310) **

^s Re-estimated by Maximum Likelihood estimation subject to autoregressive error specification.

+ Diagnostic tests from original OLS estimation. Standard errors in parentheses.

*, ** denotes significance at 5% and 1% respectively.

transformed model only accounts for serial correlation problems. Therefore the estimated parameters in the early period could still be unreliable because the failure of most of the diagnostic tests in the original equation gave reasons to question this specification over the early period.

6.3.4 Preliminary Conclusions

When the whole sample period 1968 to 1985 is used, the probit model 6.3E, which includes the lagged dependent variable and the first quarter lag of advertising looks promising. Of all the economic variables included, it is interesting to note that the price and hire purchase variables behaved well consistently. The lagged dependent variable tended to dominate the equation results and whilst the magnitude of the coefficient, when translated in partial adjustment terms, did not seem too unreasonable, this is not the sole interpretation for the lagged dependent variable. Unlike the epidemic model, information flows are given little prominence and this variable could be picking up the bandwagon or word of mouth effect. The first quarter lagged advertising variable also appeared important but not once the sample period was restricted to the first 11 years of the diffusion process, however, this conclusion should be treated cautiously given the poor statistical performance of the model specification over this restricted period as indicated by the diagnostic test statistics.

6.4 CONCLUSIONS; THE COLOUR TELEVISION RECEIVER

In comparison to the epidemic model results, the probit model seems more relevant in describing the demand diffusion equation for the colour tv receiver in the UK. The structure looks promising and worthy of further investigation. The model may not be working too well over the early period because it fails to capture the information flow aspect well enough and so may need some additional thought given to this period in the diffusion process, when lack of information may be relatively important.

The epidemic model provided some intriguing results but the volatility of the coefficients on the main variables when using different specification hypotheses and

econometric techniques, did give serious doubts about the applicability of this particular diffusion model and especially the confidence attached to the parameter estimates. This is perhaps not too surprising given that neither price or the hire purchase deposit variables were included in the model. The results from the probit model estimation certainly indicated that this could have been a serious omission. Either way, there are some encouraging results for the colour tv receiver and it would certainly be worth pursuing the role of advertising in the diffusion process further. At the very least, this work does show that previous studies which have sought to quantify the magnitude and significance of advertising when confined in an epidemic framework, need to be viewed judiciously.

APPENDIX A6

THE VARIABLES AND DATA

BACKGROUND

The introduction of the monochrome receiver has been a story of a very successful consumer leisure appliance, moving in a relatively short space of time from being a luxury item to a more or less common article in most UK households. In 1967, the proportion of the population who owned a black and white tv was estimated to be at least 86%. Throughout the 1950s and early 1960s, only monochrome sets were available in the UK. But like many products, the life cycle of this durable was curtailed by the introduction of a technologically superior product. In 1967, the BBC began colour transmission on its second channel. It soon became apparent that the colour tv receiver was replacing the older technology as the main set in UK households. In 1985 the proportion of households owning a monochrome set only, was down to approximately 13% of the population. Diagram A6.1 clearly shows this substitution process taking place. Like its early predecessor, the colour tv set proved remarkably successful, with acquisition levels reaching around 60% by the end of the first decade of the products commercial existence. At the end of 1985, a colour tv receiver could be found in at least 80% of UK households.¹

The purpose of the empirical model presented in this chapter has been to explain the spread of ownership of the first set overtime. Actually, acquisition is probably a better term to use, since individuals have the choice to purchase or rent this particular product.² This study is not concerned with this division, although it is interesting to note that the proportion renting a colour set has been a significant although decreasing proportion (in 1982, MINTEL estimated that the rental sector still accounted for some 45% of colour sets sold in the UK). The decline in importance of the rental sector will obviously reflect such factors as the increasing reliability of the product,

1. Proportion figures in this paragraph are based on licence data unadjusted for evasion.

2. In the text, ownership and acquisition will be used synonymously.

availability of credit and the falling relative price of purchase. All of which, had been working in favour of purchase over recent years.

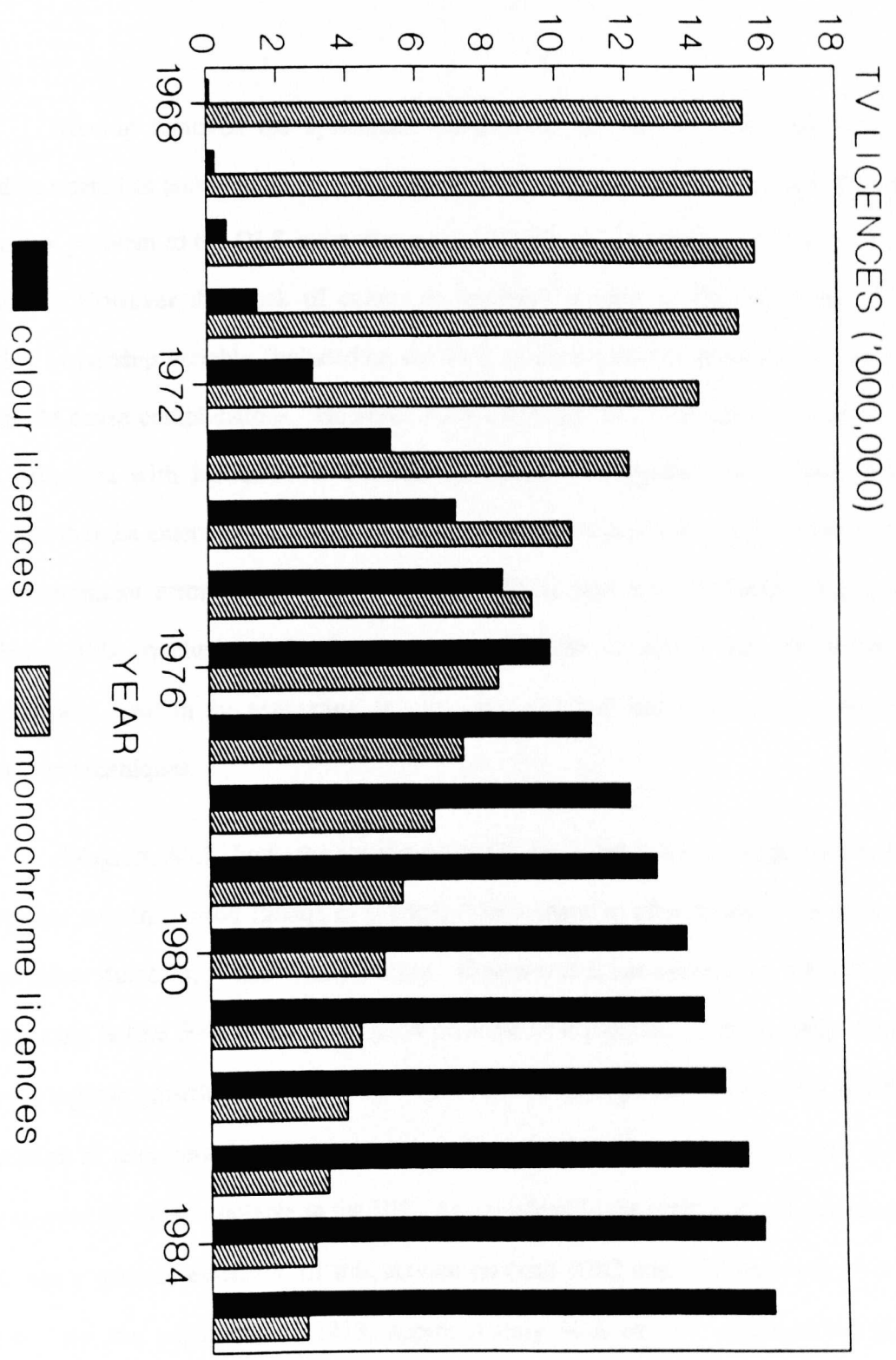
STOCK OF COLOUR TV RECEIVERS (TVL)

In order to estimate the demand diffusion model, information was needed on the stock of colour sets in existence. Sales data is available but is distorted by the inclusion of replacement and multiple acquisitions. Multiple acquisition may not be too important over the early years but by 1985, market research had estimated second colour set ownership to be approximately 39% of households. Trade estimates put the average life of a colour tv receiver at about 8 years. However the depreciation rate is unlikely to be constant overtime. At its introduction, the reliability of the product was questionable, this has since improved. Similarly, consumer expectations about technological obsolescence is likely to affect the perceived life of the product and hence the average replacement cycle. Fortunately, these problems can be avoided by using broadcasting receiving licence data which is collected by the Post Office and published on a regular basis. Obtaining an initial colour tv set, places a legal obligation on the acquirer to also purchase a colour tv licence. Of course there are problems with licence evasion but adjustment for this factor is probably a lot more reliable.

Data on the number of colour tv licences in force was collected on a quarterly basis for the period 1968 quarter 1 to 1985 quarter 4. Licence evasion will result in a systematic understatement of the true situation. Provided the measurement error is random, this problem can be overcome by econometric means. Using an alternative source of data, collected by the trade association BREMA on the number of sets in use, a comparison between the two data sets was made and an estimate of the average percentage understatement in the tv licence data calculated. This comparison was made over the period 1968 to 1982 only in order to avoid the multiple set ownership factor which was inherent in the BREMA data. This distortion was thought to be more pronounced after 1982, as noted by the trade association themselves, who found a strong

TV RECEIVERS IN THE UK 1968-1985

BROADCAST LICENCES MONOCHROME AND COLOUR



Source: Monthly Digest

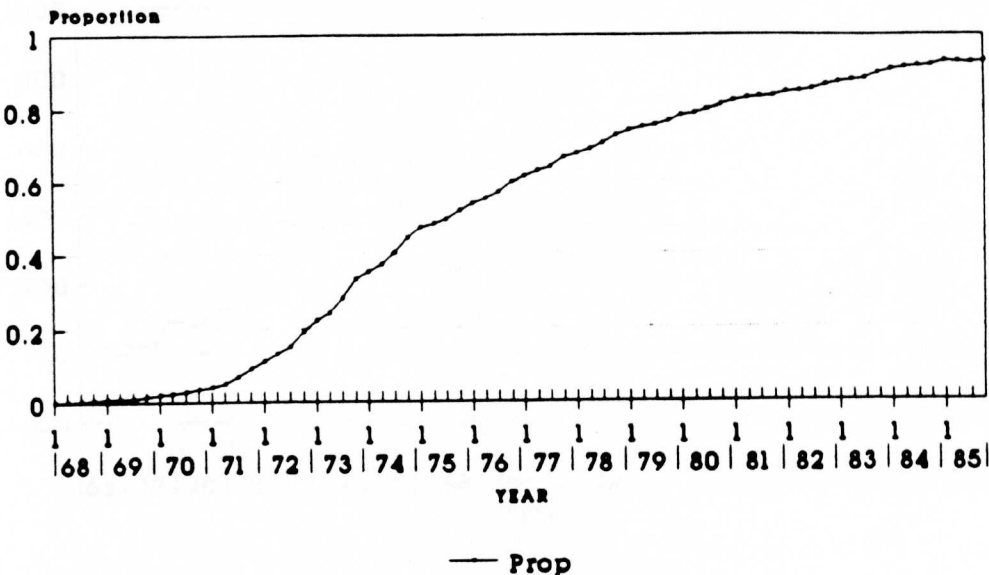
trend towards colour tv portable sets in 1983 and a rapid growth in multiple ownership in 1984. Hence the tv licence data was adjusted to account for an average understatement of 16%.

Having removed the systematic component, any further measurement error could be treated as purely random. Measurement error in the dependent variable does not cause any problem to the OLS estimation as it will end up in the disturbance term of the equation. However the stock of colour tv receivers is used in the formation of the existing ownership variable, included on the RHS of the estimating equation. Potentially this could cause complications. However early investigation of the data, comparing the OLS estimates with Instrumental Variable estimates, as suggested by Sargan (1958), indicated that the extent of the measurement error was not significant. A more formal test for measurement error proposed by Hausman (1978) was also performed and it too confirmed this conclusion. So the decision was made to accept that the extent of measurement error in the estimating equation was minimal and to proceed using OLS estimation techniques.

Diagram A6.2 shows the proportion of UK households having acquired a colour tv receiver over the period 1968q1 to 1985q4. The S shape so often found in the diffusion of consumer durables, is undeniably visible. However it is not symmetric, the inflection point occurs before 50% of the population own the new product. Consequently, merely fitting a logistic growth curve to the data would not be appropriate. Strictly, the potential population of acquirers for this particular product should account for the limited colour transmission facilities available in the UK. As explained in the main body of this chapter, there was a gradual extension of this service on both BBC and ITV channels over the period. By the beginning of 1973, approximately 90% of UK households had the technical capability to receive colour transmission on BBC and ITV channels, if a colour set was acquired. The number of demographic households was simply weighted by this increasing proportion. The second graph in diagram A6.2 shows the proportion of these adjusted households who had acquired a colour tv receiver over the period. The skewed S

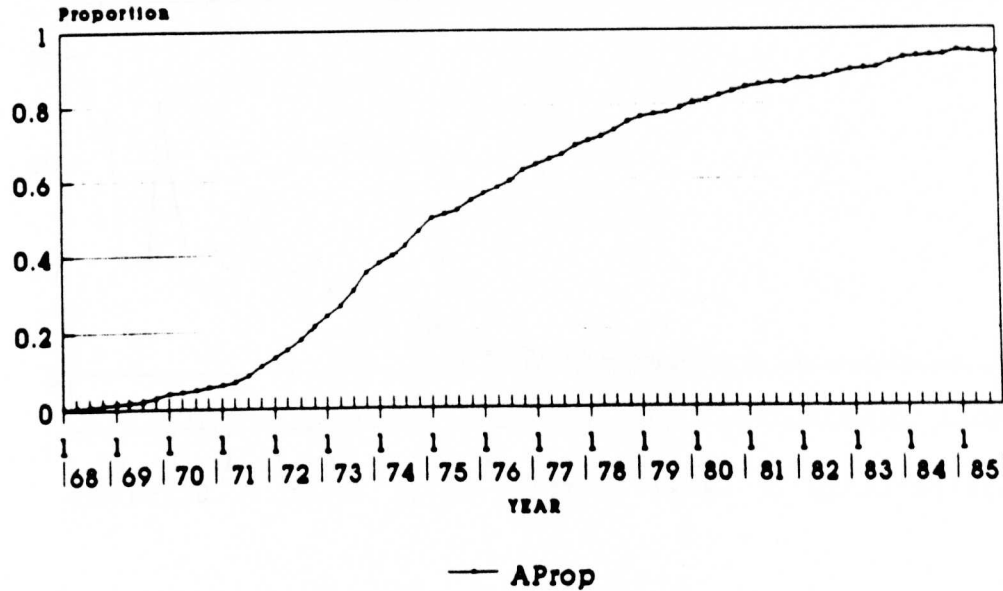
UK COLOUR TV OWNERSHIP Proportion of UK households Owning or Renting a Colour TV

A6.2



Source: Monthly Digest
Prop = $TVLI/MH$
TVLI = No. of Colour TV Licences

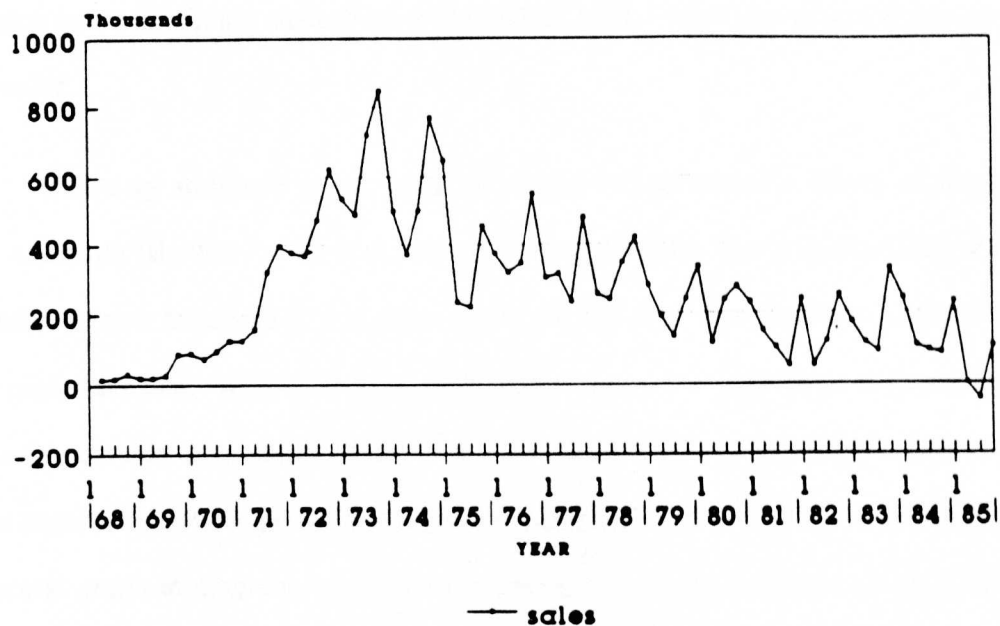
UK COLOUR TV OWNERSHIP Proportion of UK households Owning or Renting a Colour TV (Adjusted for Channel Availability)



Source: Monthly Digest, BBC, IBA
AProp = $TVLI/AMI$
TVLI = No. of Colour TV Licences

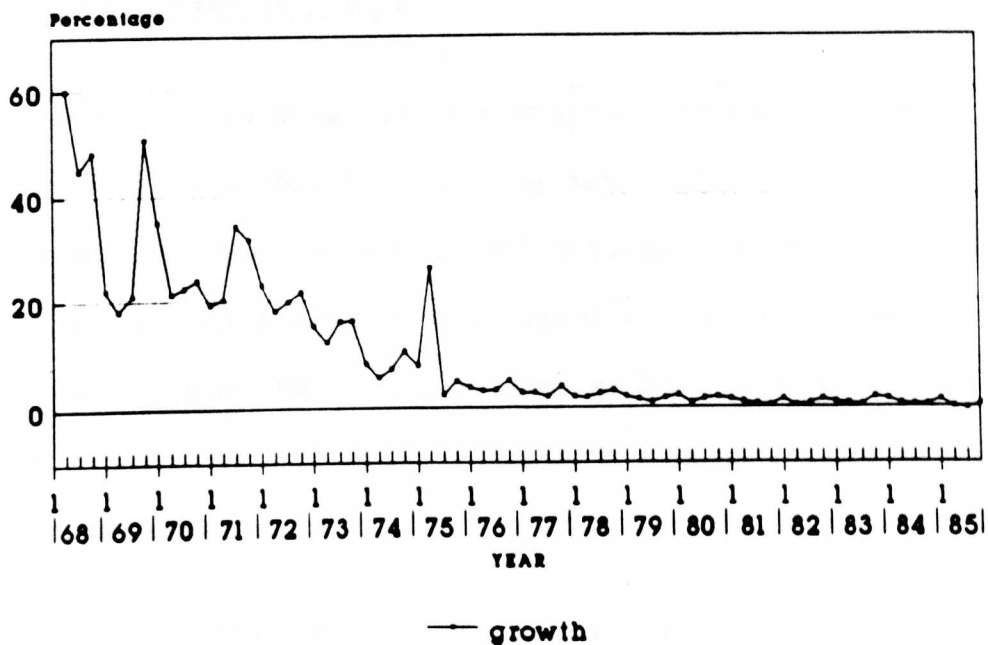
UK COLOUR TV 'SALES' First Differences in Licence Data

A6.3



Source: Monthly Digest
'Sales' TVLI - TVLI-1

UK COLOUR TELEVISION RECEIVERS Growth in Stock of Colour TV receivers



Source: Monthly Digest
growth = ((TVLI - TVLI-1)/TVLI-1)*100

shape is again clearly evident. The main difference between the two graphs in diagram A6.2 comes, not surprisingly, in the early period. The gradient of the adjusted household proportion curve is slightly steeper up to the end of 1971. After that date, the curves are very similar.

Quarterly additions to the stock of colour tv receivers are shown in diagram A6.3. Although labelled 'sales', it should be remembered that this graph actually shows the number of new acquirers of first sets only in each quarter. The seasonal nature of this data is unmistakeable. Within the year, sales peak in quarter 4 (the Christmas period) and the lowest quarterly sales occur in April to June. The long run trend in the data reveal that the number of new acquisitions reached a maximum in 1973 and declined thereafter. The second graph in diagram A6.3 displays the rate of growth in the stock of colour tv receivers. Again the seasonality is obvious but so too is the overall downward trend in the growth rate. After 1977, the growth rate more or less settles at a low constant rate, becoming almost negligible after 1981.³

ADVERTISING EXPENDITURES (A)

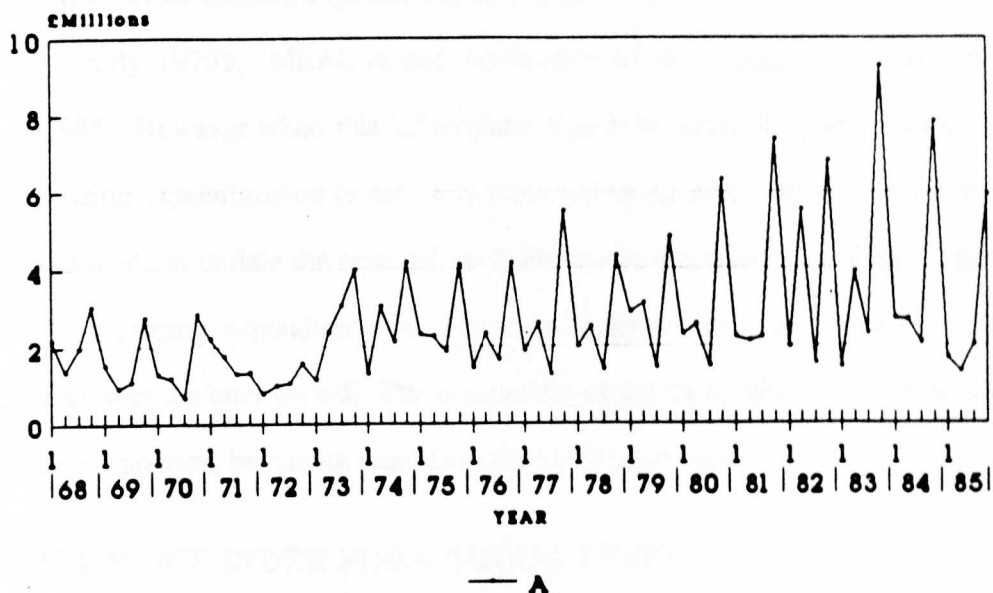
Data on total advertising expenditure on colour tv receivers by the rental and retail sector is plotted in diagram A6.4. The basic source of data for nominal expenditures is MEAL. Ideally the data should have isolated expenditures on colour tv receivers only. However this level of disaggregation was not feasible. A workable assumption had to be made that all the data referred to colour sets only. This is more likely to be true over the later period. Although far from perfect, data limitations enforced such an assumption.

The nominal data was deflated by a media cost index constructed by the Advertising Association. These indices show changes in the price of advertising in TV

³. There is one oddity in the data that needs explaining. In 1985q3, the stock of tv licences actually fell, suggesting that a number of current licence holders either did not renew their licences or disposed of their colour tv sets. This had also happened earlier in 1979 but was due to the effect of a postal strike on the data collection and so an adjustment for this factor was made. There was no apparent reason for this in 1985. Consequently this observation was left unaltered.

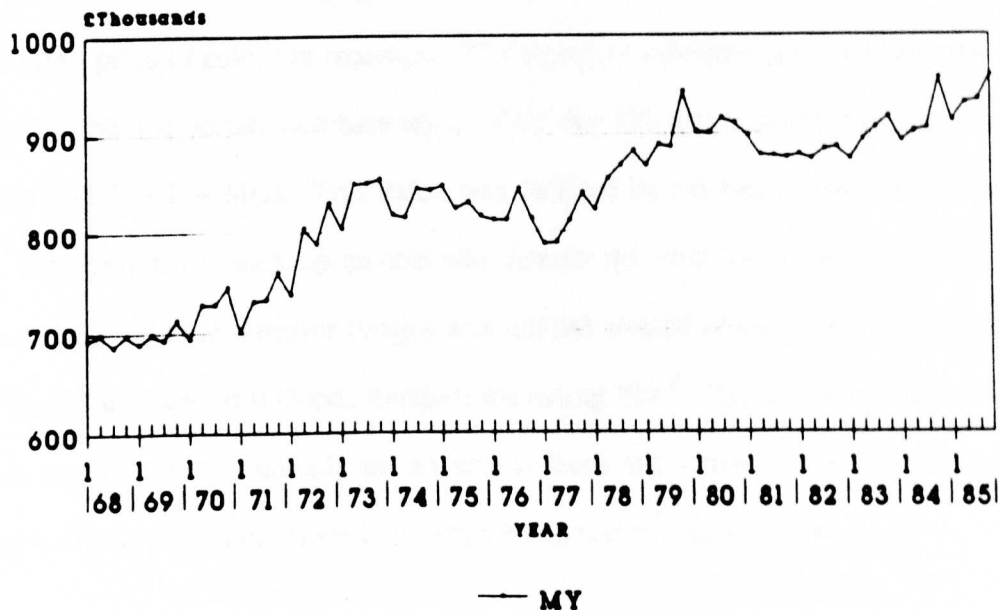
REAL ADVERTISING MESSAGES ON COLOUR TVs **Total Real Expenditure by Rental** **and Retail Sectors**

A6.4



Source: MEAL, AA
A = (NAD/API80)*100

REAL PERSONAL DISPOSABLE INCOME **PER CAPITA SEASONALLY UNADJUSTED PDI** **constant prices 1980 = 100**



Source: Monthly Digest
MY = PDI/POP

and Press media and alterations in audience size. The deflated advertising expenditures should therefore represent the real volume of expenditures in these respective media. A large proportion of advertising expenditures on tv receivers consisted of advertising in the press in the early 1970's. MEAL ceased publication of this media split from the mid 1970's to 1985. However when this information was re-introduced, approximately 60% of all advertising expenditure on tv receivers remained in the press media. On balance, a decision was made to deflate the nominal expenditures by the press index only. The real volume of advertising expenditures is plotted in diagram A6.4 and exhibits a slight upward trend over the later period. The seasonality of the data, with quarter 4 being the peak season is apparent, becoming more extreme in the later years.

RELATIVE PRICE INDEX FOR COLOUR TV (P)

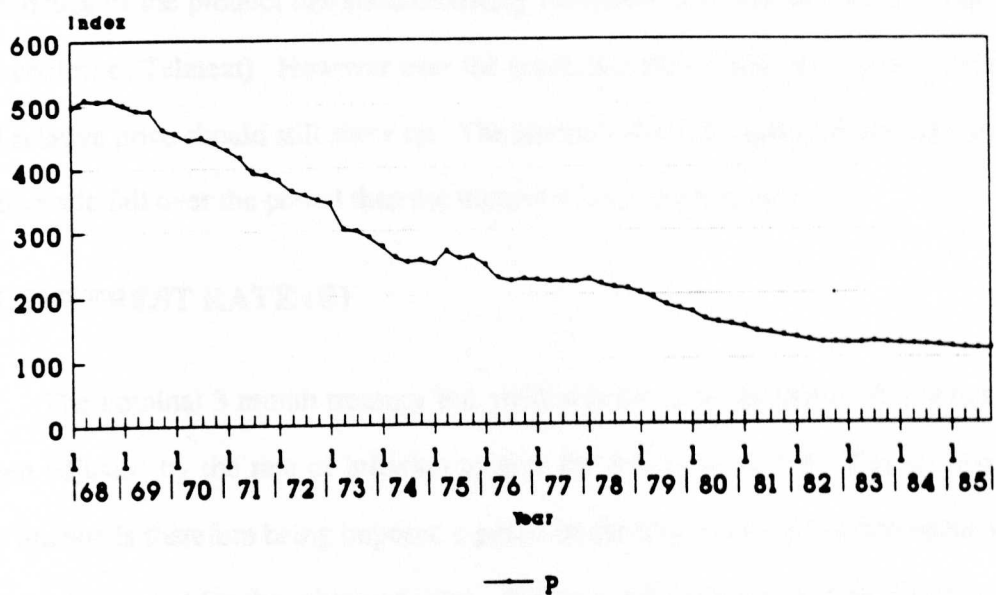
Diagram A6.5 displays two versions of the relative price term. The bottom graph shows the relative producer price index of colour and monochrome receivers (PRP). The producer price index series for monochrome sets was discontinued after 1983. The data exhibits a strong downward trend. The alternative relative price term, is the real retail price of colour tv receivers. The colour tv producer price (CPI) series was adjusted for the appropriate purchase tax or VAT rate (T) and retailers mark up on cost (MU), so $CPI(1 + T + MU)$. This index was deflated by the Retail Price Index for all items. The appropriate mark up on cost was determined from the retailers gross margin as a percentage of total turnover (wages and salaries treated as overhead, Holton 1957) for the Radio and Electrical Goods Retailers excluding Hire⁴. The gross margin data was obtained from Retailing, initially on an annual basis but latterly on a biannual basis. Missing quarterly observations were therefore estimated by interpolation.

Since the series is an average measure, changes in the sales mix of the product model range will not be distinguishable from an overall change in the price of the product. In other words, no account has been made for the fact that the 'bundle of

4. Since gross margin $\mu = (P-C)/P$ and mark up on cost $MU = (P-C)/C$, then $MU = 1/(1-\mu) - 1$.

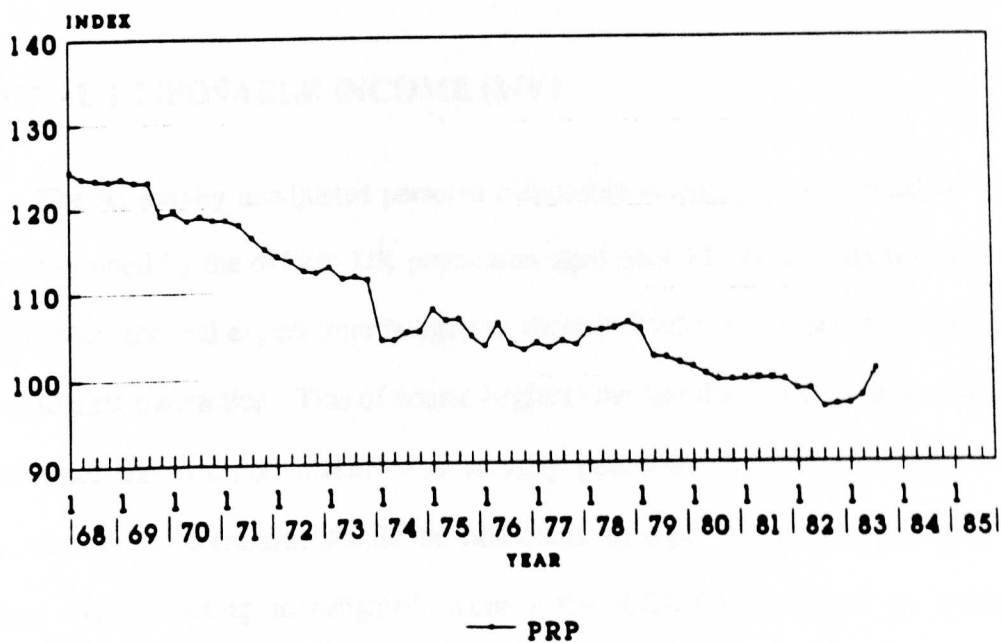
REAL AVERAGE RETAIL PRICE OF COLOUR TVS **Average Retail Price Index of Colour TVs** **deflated by Retail Price Index 1980=100**

A6.5



Source: PINNCCA, Retailing, BREMA
PI = API/rpi

RELATIVE PRODUCER PRICE INDEX OF **COLOUR AND MONOCHROME TVs**



Source: PINCCA
PRPI = CPI/BPI

characteristics' represented in models may be significantly changing over time. An observed higher unadjusted relative price may therefore be misleading, if the level of characteristics of the product has simultaneously increased (for example the inclusion of remote control or Teletext). However over the years, any significant trend in the products overall relative price should still show up. The alternative relative price series discloses a more dramatic fall over the period than the relative producer price ratio.

REAL INTEREST RATE (R)

The nominal 3 month treasury bill yield was the basic source of this series. It was then adjusted by the rate of inflation to give the real interest rate. The absence of money illusion is therefore being imposed *a priori* in the estimation and is consistent with the approach adopted for the other variables. Diagram A6.6 shows the high positive rate of interest and its upward trend since 1981. Prior to this date, the real rate of interest was mostly negative, clearly a result of the high rate of inflation during these periods.

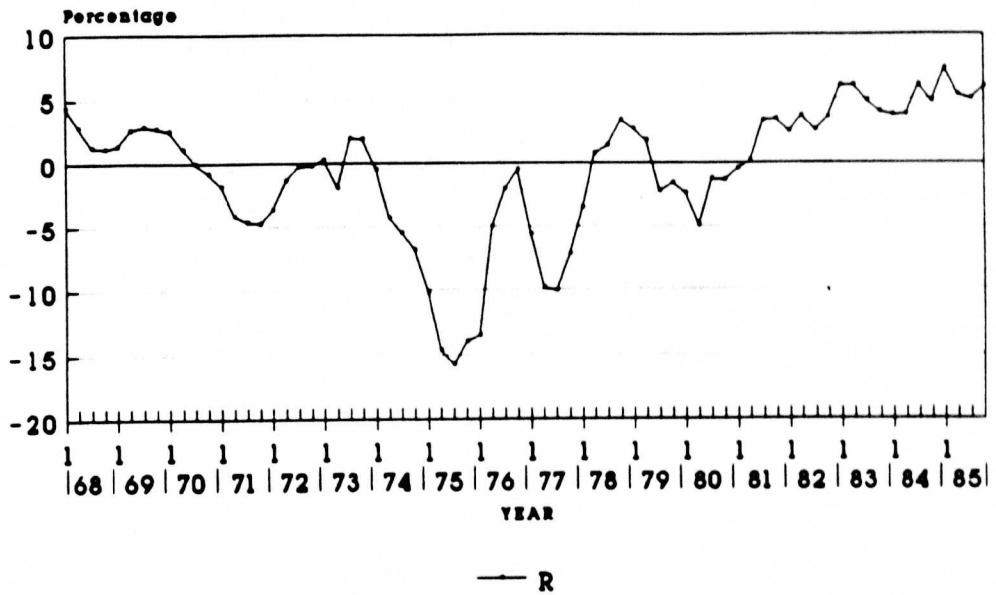
PERSONAL DISPOSABLE INCOME (MY)

The seasonally unadjusted personal disposable income series in constant 1980 prices was divided by the defacto UK population aged over 15 years. This was done in order to capture the real expenditure budgets of those individuals directly involved in the colour tv market transaction. This of course neglects the fact that children under this age may influence the 'decision maker' who actually purchases or rents a colour tv set. Strictly, the budget constraint should be household income to be consistent with the dependent variable being investigated, namely the diffusion of colour tv receivers amongst UK households. The data series used was readily available on a quarterly basis and was therefore employed as an approximation. Figure A6.4 shows that the variable exhibited an upward trend, except for the recessionary effects of 1975/77 and 1981/2.

REAL RATE OF INTEREST

Nominal 3 Month Treasury Bill Yield
less Rate of Inflation

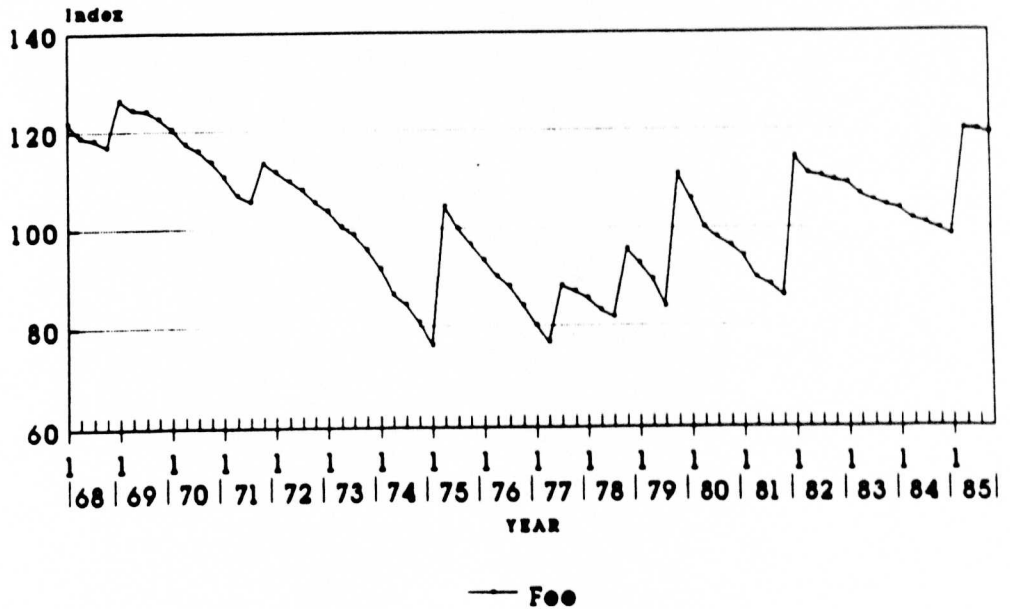
A6.6



Source Economic Trends
R = NRTB - INFL

REAL PRICE OF COLOUR TV LICENCE FEE

Colour Licence Fee Index Deflated by RPI
All Items 1980 = 100



Source: BBC
Fee = CLI/RPI

A full description of all the variables used in the empirical investigation is given in the next pages.

DEFINITIONS AND DATA SOURCES

Quarterly observations for the period 1968q1 to 1985q4. All data are seasonally unadjusted and constant price data are in 1980 prices. Standard errors are in parentheses beneath the coefficient estimates. Natural logarithmic transformation of explanatory variables are denoted by $L(\text{variable name})$.

H_t Number of households in the UK in thousands. Quarterly observations from interpolation of growth rate (Census of Population and Social Trends).

AH_t Number of UK households able to receive colour transmission service on BBC and ITV (BBC and ITA).

TVL_t Stock of colour tv receivers. Broadcast receiving licences in force for colour tv in the UK in thousands. Lagged by one month, to capture the delay in between acquisition of set and obtaining a licence (Bain 1962). Also adjusted for licence evasion, using BREMA annual estimates of number of colour sets in use. An average understatement of approximately 16%. See text for more detail (Monthly Digest).

$$OWN_t = TVL_{t-1}/AH_t$$

$$AX_t = A_t \cdot (TVL_{t-1}/AH_t)$$

A_t Real total advertising expenditures on tv receivers. Nominal advertising expenditures by both retail and rental sectors on tv receivers in thousand pounds (NAD) deflated by the press media index (Advertising Association, MEAL).

q_i Seasonal dummy quarter i

BBC2 Dummy variable taking a value of 1 when colour transmission service is available on BBC channel 2 only.

- R_t Real rate of interest. Nominal 3 month Treasury Bill yield, average discount rate expressed as a rate per annum less the rate of inflation as measured by Retail Price Index all items, RPI, (Economic Trends).
- P_t Relative average retail price index of colour tv receivers, that is producer price index of colour tv sets (CPI) multiplied by the relevant purchase tax or VAT rate and retailers margin as described in the text (AP_t) and deflated by RPI (PINCCA, retailing, BREMA).
- PRP_t Ratio of producer price index of colour to monochrome tv receivers (PINCCA).
- MY_t per capita real disposable income. Real personal disposable income deflated by defacto UK home population over 15 years in thousands pounds (Monthly Digest).
- $DPST_t$ Hire purchase series consisting of minimum legal proportion required as a deposit. As the maximum monthly repayment period also moved in line with the minimum deposit proportion, the variable simply reflected the deposit proportion (BREMA).
- FEE_t Price index of colour tv licence fee deflated by RPI (BBC Handbook).
- PCM_t Net output less wages and salaries as a proportion of total sales for the electronic consumer goods and other elect. equipment producers SIC 3454 (Census of Production).
- NOB Number of observations.
- RSS Residual Sum of Squares of the equation.
- DW Durbin-Watson statistic for 1st order serial correlation.
- D-h Durbin's h statistic for 1st order serial correlation.

LM4	Lagrange Multiplier test for residual autocorrelation up to order 4.
RSET	Ramsey Reset test using the square of the fitted values.
NORM	Jarque-Bera test for normality.
HET	Heteroscedasticity test based on regression of squared residuals on squared fitted values.
CHOW	Chow test for stability of the regression coefficients.
PRED	Predictive Failure Test, ie, Chow's second test of adequacy of predictions.

CHAPTER 7

CONCLUSIONS

At the beginning of this thesis, it was argued that research into the diffusion process and in particular the diffusion of new consumer durables and the role of advertising, had been relatively neglected by economists. The aim of this thesis has been to rectify past deficiencies by explicitly focusing upon the part played by advertising in the diffusion of new consumer durables both at a theoretical and empirical level.

To begin with, in Chapter 3, the epidemic diffusion model was used. Advertising had been incorporated into such a model already in the theoretical literature, but was limited to consideration of the profit maximising time path of advertising for a monopolist supplier only. Here, following the standard industrial economics approach, interest focused upon the profit maximising advertising sales ratio both for a monopolist and oligopolistic industry. Whilst these ratios had been derived in a static (Dorfman-Steiner) and dynamic (Nerlove-Arrow) framework, no explicit consideration had been given to the possible implications for these ratios in a world of product innovations.

The essential feature of the two period epidemic model presented in Chapter 3, was the spread of information about the new generic consumer durable by existing owners. This had a positive effect on future flow demand. However, given the assumption that individuals purchased one unit only, the population of potential buyers was finite. Consequently, increasing the number of existing owners in period 1 would reduce the number of remaining potential buyers in period 2. Both of these dynamic aspects were encompassed in the dynamic owner externality term and its sign was crucial to the first period profit maximising decision. It became apparent that in a world of new consumer durables and addressing the role of advertising, the D-S and N-A advertising sales ratios were not sufficient for profit maximisation. In the epidemic model, the advertising sales ratio could be larger or smaller than the standard ratios depending upon

the sign of the dynamic owner externality.¹ Ultimately, the sign of the dynamic owner externality rested upon the relative magnitude of the social contact coefficient and the intertemporal effectiveness of the external channel of information ie. advertising.

The monopolist supplier assumption was relaxed to see whether the special features of the epidemic model impinged upon the resulting profit maximising industry advertising sales ratio as the number of suppliers (n) changed. Intuitively, an industry advertising sales ratio decreasing in n was expected. This was due to the oligopolist's difficulty in securing all of the positive information externality in future periods. Unlike a monopolist, an individual firm in an oligopolistic industry would have to incur an additional cost to secure a share of the dynamic benefit, namely second period advertising expenditure. The signing of the derivative of the advertising sales ratio with respect to the changing number of firms was complex and so various cases were explored. The intuitive result (advertising sales ratio decreasing in n) did emerge as a special case, under the assumptions of a constant unitary advertising demand elasticity and a relatively large discounted positive dynamic owner externality. However the formal result had to be treated with caution given the externality term was in fact endogenous.

Most of the formal analysis in Chapter 3 was based upon the assumption that each symmetric firm adopted zero conjectural variations behaviour. The effect of relaxing this assumption and the likelihood of collusion was informally considered. On the whole, in the epidemic framework, the prospects for collusive behaviour looked low, except when the number of suppliers in the industry was very small and the information flow generic in nature. Recognising the threat of entry also had implications for the advertising decision. Unlike the standard view, advertising was seen as an invitation to entry and not a barrier, however this conclusion depended upon the crucial assumption that the information transmitted was generic in nature. In this case, the threat of entry in future periods would tend to lower the monopoly advertising sales ratio. In an

¹. Also with the additional condition that the goodwill depreciation rate was not 'too high' relative to the time discount factor once a stock of goodwill was included

oligopolistic industry, the effect was ambiguous. More rivals in future periods would tend to reduce the industry advertising ratio because of the difficulty in securing all of the information externality. However the negative early extraction effect (due to the finite nature of the population of potential buyers) would now be borne by more firms in the future and this would have a positive effect on advertising intensity. It was therefore not clear which effect would dominate. However, if the information transmitted was not generic in nature but firm specific instead, such that there existed loyalty effects in a firm's market share, this would provide a positive incentive for oligopolists to undertake first period advertising, once future entry was recognised.

The epidemic demand diffusion model did not possess an economic decision base. Consequently previous authors had turned attention towards the use of an alternative probit based diffusion model. However no consideration had been given to the role of advertising in such a framework. In Chapter 4 advertising was incorporated into the probit model through the individual's profitability condition. Thus the determination of the critical value became dependent upon total industry advertising expenditures and so total advertising entered into the stock demand function. At any point in time, current flow demand would depend not only upon current decision variables but also on the existing level of ownership.²

The essential feature of the probit model was the finite population of potential buyers and so the diffusion rate was likened to the rate of extraction of a non renewable mineral resource. Given consumers holding myopic price expectations, a monopolist producer could exploit the opportunities in this model for intertemporal price discrimination. The result being a larger first period price cost margin as compared to a monopolist who ignored the dynamic implications of his decisions.

The negative early extraction effect and the price discrimination possibilities of the probit model also impinged upon the profit maximising advertising sales ratio in the

2. Past advertising expenditures would also enter directly, if a goodwill stock of advertising concept was used.

first period. The net effect of these two additional terms was not unambiguous and rested upon the ratio of the responsiveness of current flow demand with respect to current decision variables relative to the ratio of the responsiveness of current flow demand with respect to the lagged decision variables. When an additional dynamic effect of advertising through a stock of goodwill was also included, then this positive dynamic effect could potentially reduce the negative early extraction factor. However unlike the N-A condition, the goodwill sales ratio in this probit model would still need to account for the intertemporal price discrimination possibilities inherent in the model. So once again the D-S and N-A expressions were not sufficient for profit maximisation once attention was turned to the explicit consideration of the diffusion of new consumer durables. The effect of a changing number of suppliers on the industry advertising sales ratio could not be rigorously shown. However, at an intuitive level, the price cost margin was expected to be lower and the advertising intensity higher. This result was likely given the finite nature of the population and that the opportunity cost of early extraction would be borne by all the firms in the next period. This was likely to provide an incentive to race to extract consumers in earlier periods and unlike the epidemic model, there was no offsetting information externality to consider.

Having looked at some of the theoretical implications of incorporating advertising into each of the competing demand diffusion equations and including a supply side, attention was turned to the empirical stage of the investigation. No previous empirical examination of advertising in the diffusion process existed in the economics literature (other than an investigation of the coffee and tea market). However a few studies had been undertaken by marketing researchers. Generally their objective was to forecast future sales of the new product and little attention was given to testing the econometric specification hypothesised. From an economist's point of view, it is the effects of variables such as advertising which are important. The magnitude and significance of the coefficient on the explanatory variables are of interest within their own right. Unfortunately, these estimated parameters will be unreliable unless the model has

been correctly specified. Thus it is imperative to apply the econometricians diagnostic tools.

Two products were chosen for the empirical investigation, the video cassette recorder and colour television receiver. Estimation commenced with the epidemic model to see whether the data accepted this particular specification. It was argued that the application of the epidemic model was likely to be of limited use only, whereas the probit model could be more generally applied. Using data on the VCR in Chapter 5, some interesting results were produced using the epidemic specification. Both the existing ownership and current advertising variables had a positive and statistically significant effect on the diffusion process. It was found that advertising entering indirectly through the social contact coefficient proved superior to an epidemic structure in which advertising entered directly into the equation. The choice of the particular route for advertising was crucial, since the estimated parameter on the existing ownership variable was particularly sensitive to the structure adopted. Adding additional goodwill effects for advertising did not appear necessary, although given that advertising already had a lagged effect in the epidemic model (indirectly via the existing number of owners, it would be expecting a lot of the data to distinguish these dynamic factors.

The alternative probit model did not perform too well, with the magnitude and statistical significance of the estimated coefficients on the economic variables being particularly sensitive to the precise equation specification. Only the lagged dependent variable (showing the number of owners to non owners) seemed to be of any significance and this variable could have been picking up the importance of existing owners in transmitting information about the product. Overall these results highlighted the role of the information variables, ie. existing owners and advertising in the diffusion of the VCR in the UK. However, the estimation of the models did not take account of supply side factors and in particular the possible endogeneity of the advertising variable.

In Chapter 6, the colour tv receiver was investigated. The epidemic model when using the whole sample period 1968 to 1985, raised doubts about the adequacy of this framework for this particular product. The data was unable to distinguish whether advertising entered directly into the equation or indirectly through the social contact coefficient. Again this ambiguity was serious, as the estimated coefficient on the existing ownership variable was particularly sensitive to the specification adopted.

As the extent of information about the new product would be of more significance during the early period, the sample period was arbitrarily restricted to the first 11 years of the diffusion process. Re-estimation on this shortened sample, raised further questions about the suitability of the epidemic hypothesis. In the whole period, the first quarter lag of advertising was the preferred advertising variable. However in the restricted sample, the current variable performed better. Further, once the possibility of simultaneous equation bias was accounted for by using TSLS estimation, then the statistical performance of the advertising variable was more debatable. Overall the epidemic model did not appear to be an adequate representation of the demand diffusion equation for the colour tv receiver in the UK. Given the sensitivity of the statistical significance and magnitude of the estimated parameters to the econometric estimation method used, any conclusions on the role of advertising in this particular framework must be viewed with caution.

In contrast to the VCR, the probit model performed better relative to the epidemic one using data on the colour tv receiver. Although the lagged dependent variable was again the dominating explanatory factor, other economic variables especially relative price and hire purchase restrictions were influential in the diffusion process. Current advertising was not found to be a relevant explanatory variable, but the first quarter lag of the advertising variable had a positive and statistically significant effect. Consequently the demand diffusion equation would form part of a recursive system, hence there was no problem with simultaneous equation bias. Again the sample period was restricted to the first 11 years. In the shorter period, the probit model showed signs

of mis-specification and advertising was no longer significant in explaining the diffusion process. It is possible that the probit model during the early period fails to capture the information transmission process adequately and this is more likely to be of consequence at the beginning of the diffusion process. Nonetheless, the probit framework did show the importance of economic variables such as price and hire purchase restrictions in the diffusion process and the exclusion of such variables (as in the epidemic framework) could be a serious omission.

It is interesting to note that both of the information variables (advertising and existing ownership) were particularly important in the diffusion of the VCR as indicated by the relatively better performance of the epidemic model. The coefficient on the existing ownership variable was generally larger in magnitude and statistical significance than for the colour tv epidemic equation. It is feasible that being a radically new good, lack of information could be a considerable restraining factor on the diffusion process. Further, as the data suggested that advertising entered indirectly through the social contact coefficient, this would seem to support the view that individuals will need additional information from an unbiased source, before becoming fully convinced of the advertiser's claims. Again this would seem especially reasonable for a radically new product. However later on, the omitted economic variables may take precedence, thus explaining why the epidemic model's predictive ability was not too good. In contrast, the colour tv receiver was a technically superior product to the existing monochrome receiver. Consequently, even in the early period, the majority of the population would have some information about the television set in general. Therefore the information variables may not be as important as the economic variables such as relative price or hire purchase restrictions, which may be why the probit model performed relatively better.

It does seem that the significance of advertising in the diffusion process may depend upon the nature of the product being investigated. Therefore previous studies which have found a positive and significant effect of advertising in an epidemic framework need to be treated with some caution, especially since the level of diagnostic

testing of the hypothesised model was minimal. The inclusion of other economic variables should not be overlooked. The probit model appears to be a better starting point and further research should concentrate upon incorporating the information variables in a more satisfying manner, although as indicated earlier in this thesis, the researcher will be limited in this respect by the availability of an appropriate data set. Finally, the competing demand diffusion models could also be applied to a horizontally differentiated good (eg. microwave oven) to see whether the probit based model is in fact more generally applicable as expected.

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